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EXTRACTION OF THE GUINEA WORM.

From an engraving by J. H. Jördens (1802.)

HUMAN HELMINTHOLOGY

A MANUAL FOR CLINICIANS, SANITARIANS AND MEDICAL ZOÖLOGISTS

BY

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PREFACE.

As an investigator in the field of medical parasitology for nearly two decades and a teacher of the subject to physicians and zoölogists, the author has followed closely the important steps in the development of the subject. In no phase of medical zoölogy, both in its biological and its clinical aspects, has greater progress been made than in helminthology. Thus far, however, no attempt has been made to correlate the available information, much of which has been published in inaccessible journals, and to bring it together into a manual which would meet the needs of the parasitologist. The present volume is the result of the author's own need for a teaching and reference text on the subject. It is also significant that certain of the author's colleagues as well as many of his students have urged him to make available for them the subject-matter of human helminthology. This has been no easy task, especially since the field includes both theoretical and practical problems. It is felt, however, that the form in which the data have been compiled will serve this two-fold end and will, furthermore, make the information available alike to the clinician, the sanitarian, and the medical zoölogist. Although each of these workers, from his peculiar vantage point, is primarily concerned with one particular aspect of the subject, he is also interested in the problem as a whole, and will appreciate the need for an all-around presentation of the available information in the field.

Of necessity the author has depended on the work of his colleagues for much of the evidence and many of the views expressed in this volume. Sincere thanks are here expressed to those who have either directly or indirectly contributed to the contents or form of the manual. The difficulties of obtaining adequate and well-balanced illustrations have been considerable. Those who have generously placed their original or published figures at the disposal of the author deserve no small share in whatever of credit may come

2325

from the adventure. Grateful thanks are also due to those who have assisted in typing the manuscript, in revising the proof and in compiling the index. Last, but not least, the courteous personal coöperation which the publishers, Messrs. Lea and Febiger, have provided, and the high ethical standards which they have consistently maintained during the five-year period of writing and of publishing the volume call for the highest praise.

Ernest Carroll Faust.

New Orleans, La.

CONTENTS.

SECTION I.

THE SCOPE OF HELMINTHOLOGY.

CHAPTER I.

THE PHENOMENON OF PARASITISM IN HELMINTH GROUPS.

CHAPTER II.

THE INTER-RELATION OF THE HELMINTH PARASITE AND ITS HOST.

CHAPTER III.

THE FOUNDATIONS OF HELMINTHOLOGY.

CHAPTER IV.

THE NOSOGEOGRAPHY OF HELMINTHIC INFECTIONS.

CHAPTER V.

THE SCIENTIFIC NOMENCLATURE OF HELMINTH PARASITES.

CHAPTER VI.

THE LITERATURE OF HELMINTHOLOGY.

SECTION II.

THE PLATYHELMINTHES OR FLATWORMS.

CHAPTER VII.

THE FLATWORMS AS A GROUP.

CHAPTER VIII.

TREMATODES OR FLUKES.

CHAPTER IX.

TREMATODES OR FLUKES. CLASSIFICATION.

CHAPTER X.

Trematode Parasites of the Blood System.

CHAPTER XI.

The Human Blood Flukes.

CHAPTER XII.

The Human Blood Flukes (*Concluded*).

CHAPTER XIII.

Trematode Parasites of the Intestinal Tract, Biliary Passages and Lungs.

CHAPTER XIV.

TREMATODE PARASITES OF THE INTESTINAL TRACT, BILIARY PASSAGES AND LUNGS (*Concluded*).

CHAPTER XV.

THE CESTODES OR TAPEWORMS. STRUCTURE AND LIFE HISTORY.

CHAPTER XVI.

THE CESTODES OR TAPEWORMS. CLASSIFICATION.

CHAPTER XVII.

THE PSEUDOPHYLLIDEAN CESTODES.

CHAPTER XVIII.

THE CYCLOPHYLLIDEAN CESTODES.

CHAPTER XIX.

THE CYCLOPHYLLIDEAN CESTODES (*Concluded*).

SECTION III.

THE NEMATHELMINTHES OR ROUNDWORMS.

CHAPTER XX.

NEMATHELMINTHES OR ROUNDWORMS.

CHAPTER XXI.

THE NEMATHELMINTHES OR ROUNDWORMS (*Continued*).

CHAPTER XXII.

The Nematodes or True Roundworms.

CHAPTER XXIII.

The Trichosyringate Nematodes.

CHAPTER XXIV.

THE MYOSYRINGATE NEMATODES.

CHAPTER XXV.

THE MYOSYRINGATE NEMATODES (*Continued*).

CHAPTER XXVI.

THE MYOSYRINGATE NEMATODES (*Continued*).

CHAPTER XXVII.

THE MYOSYRINGATE NEMATODES (*Continued*).

CHAPTER XXVIII.

THE MYOSYRINGATE NEMATODES (*Concluded*).

CHAPTER XXIX.

GORDIACEA OR "HAIRWORMS."

CHAPTER XXX.

ACANTHOCEPHALA OR THORNY-HEADED WORMS.

SECTION IV.

HELMINTHOLOGY AND THE DIAGNOSTIC LABORATORY.

CHAPTER XXXI.

The Equipment Required for the Diagnosis of Helminthic Infections.

CHAPTER XXXII.

The Collection, Preparation and Preservation of Helminthological Material.

CHAPTER XXXIII.

The Identification and Differential Diagnosis of Helminth Parasites and Their Eggs.

CHAPTER XXXIV.

Intermediate and Reservoir Hosts Involved in Human Helminthic Infections.

HUMAN HELMINTHOLOGY.

SECTION I.

THE SCOPE OF HELMINTHOLOGY.

CHAPTER I.

THE PHENOMENON OF PARASITISM IN HELMINTH GROUPS.

INTRODUCTION.

Parasitism exists in so many groups of the Animal Kingdom and involves so many thousands of species of animals that it has been a subject of interest and study from the earliest times. Those species of animals which are parasitic on or in the human body and thereby bring about human disease are of special concern to the medical profession. However, in order that the student of medicine may have an intelligent comprehension of the strictly human parasites, it is essential that he view in brief the phenomenon of parasitism as a whole and the relationship of the human parasitic species to the more inclusive subject of parasites as a physiological group.

First of all the parasite must be distinguished from the predacious organism. The *parasite* lives at the expense of another organism which harbors it and which is commonly called its *host*. If it is well adapted to the host, no appreciable harm results. On the other hand the *predacious organism* kills the animal which it attacks, either at once or piecemeal, in order to devour it. There are many gradations between the predacious animal and the well adapted parasite. Various names have been applied to those species which on the one hand, feed only upon the waste products of the host, and, on the other, are actually helpful to the host. The former are usually referred to as *commensals*, the latter, as *symbionts*. As an example of the former may be mentioned the common colon amœba of man; as an example of the latter, the intestinal flora which preserves

a constant hydrogen-ion concentration and, indirectly at least, serves in the digestion of food and passage of water through the intestinal tract. At times *Ascaris lumbricoides* appears to be a harmless commensal; at other times it is a dangerous parasite. Since it is of great importance for the clinician to know, wherever possible, what the relative danger is from infection with a particular organism found in the human body, an attempt will be made in the pages referring to individual species of parasites to evaluate the relative degrees of pathogenicity of these "guests" to their "hosts." While there is a wide variation existing all the way from the harmless commensal to the poorly adapted parasite which produces a diseased condition of the host, it is convenient to designate all of these types of parasites as "*guests*," without reference to their degree of parasitism. The term "guest" is the more justifiable since certain species are at times entirely harmless and at other times dangerous to the life of the host.

Parasitism comprehends "host" and "guest" relationships in both the Animal and the Plant Kingdoms. A plant parasite (*phytoparasite*) may be parasitic on another plant, as, for example, the barberry rust (*Puccinia graminis*) on grain, or the dry rot (*Volutella fructi*) on the apple; or it may parasitize an animal host, as, for example, the fungi which produce the various mycoses of man, such as actinomycosis and Madura foot. Likewise, animal parasites (*zoöparasites*) may parasitize plants, as, for example, the thousands of species of insects which live upon plants of economic value to man; or they may be adapted to a life of parasitism in animals, as, for example, the hookworm in man. An interesting example where a zoöparasite utilizes a plant as an object on which to encyst, in order that it may be transferred passively to man who consumes the vegetable in the raw state, is found in *Fasciolopsis*, the giant intestinal fluke. The object of such a transfer which is purely mechanical is referred to as a *vector* or mechanical agent.

If an organism lives entirely on dead tissue or food it is referred to, not as a parasite, but as a *saprobiont* or a *saprophage*. In case this waste consists of fecal material the organism is a *coprobiont* or a *coprophage*. If the organism in these instances is an animal species it is designated in the first case as a *saprozoite* and in the second case as a *coprozoite*. If the food consists of dead or dying tissue it may be spoken of as a *phagozoite*. Certain organisms which are accidentally *en transit* through the digestive tract and are diagnosed from examination of the stool are conveniently referred to as *fecal contaminators*. Such is the egg of the nematode species, *Heterodera radicicola*, at times found in the fleshy roots of vegetables consumed by man and at one time incorrectly diagnosed from the resemblance of its egg to that of *Enterobius* (*Oxyuris*) *vermicularis* as *Oxyuris incognita*.

Some organisms which depend on others for food are entirely *ectoparasitic.* The feather lice of birds (Mallophaga) live entirely on the filth accumulated among the feathers of their host. The sucking lice (Anoplura), fleas, bedbugs and biting Diptera are all ectoparasitic, but secure their nourishment from the blood of the host. Other organisms are *endoparasitic,* that is, parasitic within the host species. Those living free in the lumen of the intestine are not actual endoparasites but are popularly referred to as such. Those attached to the intestinal wall or even more intimately parasitic in the tissues of the host as, for example, the hookworm or the human blood fluke, are true endoparasites. Organisms which are able to live either a free or a parasitic existence are spoken of as *facultative parasites;* those which have become completely dependent on their host for existence are designated as *obligatory parasites.*

Parasites are most commonly found in three large divisions of the Animal Kingdom—the Protozoa, or one-celled organisms, the Helminthes, or worms, and the Arthropoda, or invertebrate species with articulated legs.

The groups of parasites considered in this book are commonly referred to as "helminths," or worms. The term "helminth" does not connote a single group or phylum of the Animal Kingdom, but refers to two large phyla, the **Platyhelminthes**, or flatworms, and the **Nemathelminthes** or roundworms. These groups differ from one another both in external appearance and in fundamental organization: the flatworms have no body cavity and their digestive tract when present consists only of a blind pocket;[1] the roundworms (*sensu stricto*) have a body cavity and a complete digestive tract with both oral and anal openings. The flatworms are usually hermaphroditic; the roundworms are usually diecious. The two groups have the common characteristic in that a majority of the flatworms and a very large part of the roundworms have become adapted to a parasitic existence, and that their reproductive products have become disproportionately multiplied when compared with the majority of free-living species, thus ensuring a greater degree of certainty in propagation of their kind.

In the case of the **Platyhelminthes**, or flatworms, two of the three classes, the **Trematoda**, or flukes, and the **Cestoda**, or tapeworms, are exclusively parasitic, while the third class group, the **Turbellaria**, consists almost exclusively of free-living organisms. While there are thousands of species of parasitic **Nemathelminthes**, or roundworms, there is an even larger number of species of this phylum which are free-living forms. The **Acanthocephala**, of doubtful relationship, but usually placed in a separate class under the **Nemathel-**

[1] Trematodes, such as *Balfouria monogama,* which have an anus, are an exception to this general statement.

minthes, are exclusively parasitic. In addition to these two phyla the term helminth usually includes the phylum **Annelida**, to which the earthworms and leeches belong. The earthworms are practically all free-living organisms; the leeches are ectoparasitic helminths.

THE ADAPTATION OF HELMINTHS TO A PARASITIC EXISTENCE.

Parasitism undoubtedly began as a chance contact of one organism with another, the latter being merely a vehicle transporting the former from one free-living feeding-ground to another. Sooner or later the "guest" came to partake of food procured by the host, becoming more and more dependent on such food and gradually changing from an ectoparasitic to an endoparasitic existence. In some cases the "guest" began to consume the tissues of the host, first in a very superficial way, but later by the use of suctorial organs developed for such feeding or by actual penetration into and residence in the tissues of the host, resulting in a very degenerate and dependent existence for the parasite. Such forms as those which are able to live in the blood or lymph systems (*filariæ* and blood flukes) or which have their residence in the muscular tissue (*Trichinella*) or attached to the peritoneum or pleura (hydatid cyst) are usually the most highly modified (*e. g.*, simplified) and are, therefore, regarded as the oldest parasitic species. Other species which live in the mouth or bladder of the host or on the surface of the body (as, for example, monogenetic trematodes on aquatic animals) are frequently very young in parasitism, as demonstrated by their relatively slight modifications from the archetype of the group. It frequently happens among the helminths that while the adult worm may be only slightly modified by its parasitic position and habits, the larval or intermediate stage has become remarkably simplified. This is particularly true of the digenetic trematodes, where the larva, upon hatching from the egg, penetrates a snail and becomes modified into a hollow sac (the sporocyst) which, in many species, gives rise by sexual processes to a second generation of simple sacculate sporocysts. These, in turn, produce the free-swimming larvæ (cercariæ), which invade other hosts and grow into the mature hermaphroditic worms. Likewise the larval stage of the tapeworm (*Cysticercus, Cœnurus* or *Echinococcus*) is much more highly modified than the adult form.

As has been previously stated, the change from a fortuitous free-living existence to one in which protection from enemies and a good supply of food are guaranteed, has brought about profound modifications in the structure of the helminth parasite. In the first place there is the reduction in the organs of locomotion, except during free-living (larval) phases of the life cycle, where in the parasitic

Platyhelminthes the ectoderm may be ciliated (miracidium, hexacanth embryo). Even more striking is the reduction in the organs of alimentation. In the tapeworms the digestive tract has entirely disappeared except possibly in a very early larval stage; in the hermaphroditic adult trematode it consists of a blind gut, while in the *parthenitic stages*, (*i. e.*, those having parthenogenetic development) in the mollusc, the gut is further simplified (in the redia) or completely eliminated (in the sporocyst). Where no organ of digestion is present the host lies in a medium of digested or semi-digested food which may be directly absorbed by the parasite. Such larvæ as live in the inter-hepatic lymph spaces of molluscs (the condition obtaining during the parthenogenetic stages of all digenetic trematodes) or in the blood stream (microfilariæ), muscle fascia (*Sparganum*) or musculature (*Cysticercus, Trichinella* larvæ) of vertebrates, are in a habitat where they are constantly bathed in an ample supply of highly nutritious predigested food. The entire outer layer of the parasite in such a location usually serves as an absorptive surface and is usually much more permeable than is that of the adult worm. Adult worms which live in an equally favorable medium for nourishment, such as the blood flukes in the hepatic portal system and the various species of liver flukes in the bile tracts, are also provided with a soft thin integument, which undoubtedly serves in part as a means of food absorption for the organism.

On the other hand, helminth parasites residing in the intestinal lumen have become highly modified as regards their outer integumentary covering. This layer has become adapted to two ends: (1) that of protecting the organism from the digestive action of the intestinal juices and the abrasive action of food and roughage passing through the gut, and (2) that of attachment. The integument of intestinal worms is usually thick and impermeable. During the life of the parasite it serves as a highly resistant protective covering for the vital tissues of the worm. But upon the death or even narcosis of the parasite the worm is rapidly digested, as, for example, after administration of carbon tetrachloride in hookworm and *Fasciolopsis* infections. In the case of larval flukes which have to pass through the stomach in order to reach the intestine or bile passages for further development, a cyst capsule is provided as a protection from the gastric juice. On reaching the duodenum this capsule is rapidly digested away and the larva crawls out, none the worse for its temporary imprisonment. Certain amphistome species in ruminants and gnathostomes in cats, dogs and hogs live attached to the stomach wall. In consequence they are provided with an extremely thick resistant integument, impregnated with a chitin-like substance of an especially impermeable character. Many trematodes living in the intestinal tract are provided with a spinose integument. These spines may be acicular, dentate or placoid in

type and are imbedded firmly in the integumentary matrix or rooted into the subintegumentary layer. These scales guard against abrasion of the outer layers of the parasite. The Oriental liver fluke, *Clonorchis sinensis,* which was probably an intestinal parasite before it became a bile-tract inhabitant, possesses a spinose integument during its larval period, in fact until it has become safely located far up in the distal passages of the biliary canals. The adult worm, however, is entirely aspinose.

Modifications of helminth parasites for purposes of attachment to the intestinal wall of their hosts have developed on the one hand as *acetabula* or sucking organs and on the other as hooks, the latter being most highly developed at the head end of the worm. Acetabula are found in all of the adult flatworms which parasitize man. In the flukes they consist of two suckers on the ventral side of the body of the worm, one anterior and one more or less posterior in position. The relative development of these two sucking cups varies in different species. In the case of the human tapeworms they consist either of a sucking trough or groove (*Diphyllobothrium* species) or of four cups at the "cephalic" end of the worm. In some of the tapeworms and in many of the nematodes which are parasites of the human intestine hooks are situated in or around the anterior end to assist in attachment. In the pork tapeworm (*Tænia solium*) these hooks are arranged as a crown or circlet on the rostellum, anterior to the sucking cups. In the dog tapeworm they occur in several rows around a proboscis-like organ at the anteriormost part of the body, which may be inverted or everted as the parasite requires. A similar arrangement is found at the anterior end of the head of the thorny-headed worm (*Macracanthorhynchus hirudinaceus*) commonly found in the pig, and rarely parasitic in man. The hookworm has a series of "upper teeth" just within its buccal capsule which serves to attach the worm firmly to the mucosa of the host's intestine. *Triodontophorus* has a buccal armature of tooth-like structures directed anteriad, and serving both for tissue abrasion and for anchoring of the parasite.

In some of the helminths there have been developed in the vicinity of the mouth secretory glands which serve in establishing the worm in a favorable habitat, or aid in supplying food to the worm. In the trematodes these glands are most common in the cercarial stage and serve the purpose of penetrating the outer tissues of the host. They consist of paired unicellular glands, with ducts which open through reinforced capillary tubules on either side of the mouth; they secrete a histolytic substance which digests a microscopic channel in the host tissue through which the worm may pass, either to the venous blood system of the host, as in the blood flukes, or to a favorable location for encystment in the flesh, as is the case of *Clonorchis* larvæ in fishes and *Paragonimus* larvæ in crustaceans.

Such glands disappear when their temporary function has been served. Some adult flukes also have clusters of glands in the region of the mouth but their use is not well understood. In the case of the hookworm there are glands present in the region of the buccal opening which possibly have an anti-coagulating action, so that the worm, when once attached to the intestinal mucosa of the host by its buccal armature, may have a continuous supply of uncoagulated blood as well as mucosa cells for its food.

The by-products of the internal helminth parasites may be grouped into two classes: (1) The ordinary katabolic wastes produced by the worm, which may or may not be harmful to the host, and (2) specially elaborated secretions, which have a deleterious effect on the host. If the worm lives in the digestive tract its waste products ordinarily pass out with the fecal exudate and, unless there is an overwhelming infection, little harm to the host results. Certain worms, however, either firmly attached to the intestinal wall or resident in the more intimate tissues of the body, discharge secretory products which are absorbed into the tissues and which are believed to produce very definite local, generalized, or referred symptoms. Thus the hookworm and the broad fish tapeworm are the cause of a secondary anemia which at times simulates primary anemia in its severity. The blood flukes and *Trichinella* larvæ cause a profound eosinophilic reaction. *Ascaris, Trichocephalus* and *Hymenolepis* give rise to reflex symptoms, particularly among small children. *Ascaris* at times gives rise to anaphylactic reactions and to severe hematuria.

All of these structural adaptations for protection against the digestive and abrasive processes constantly at work in the intestinal lumen of the host, as well as those assisting the worm to secure a better attachment to host tissues, are to be reckoned with by the clinician in estimating the seriousness of a particular infection and even to a greater degree in therapeutic procedure. Since the integument of most of the adult worms has been developed to resist action of the digestive juices of the host's body, it also resists the action of most of the drugs which are in common use by the clinician. Whether the worm lies free in the intestinal lumen, as *Ascaris* usually does, or attached to the intestinal wall, as the hookworm, tapeworm, and *Fasciolopsis,* or imbedded in the intestinal mucosa, as *Metagonimus* and *Heterophyes,* or has its head deeply inserted into the intestinal wall, as *Trichocephalus,* a drug to be potent must be (1) either anesthetic or lethal to the worm, and (2) at the same time, must be capable of reaching the place where the head of the worm is attached, so that it will be absorped into the inner soft tissues of the worm, causing the muscles to relax and the normal activities of the worm to cease. Unless a drug fulfils these requirements it is valueless as an anthelminthic. This same requirement

applies also to the blood flukes and the "liver flukes" (*e. g.*, bile-duct flukes), namely, that the drug, in order that it may be effective, must actually reach the focus of infection in anesthetic or lethal doses. Thus oil of chenopodium is less effective than carbon tetrachloride in the treatment of hookworm- and *Fasciolopsis-* infection than it is in ascariasis, since both the hookworm and *Fasciolopsis* have their softer internal tissues protected by having their orifices attached to the intestinal mucosa, necessitating the use of a drug which first is absorbed by the intestinal mucosa before it is effective as an anthelminthic. *Trichocephalus* is not affected by either of these drugs, since its position of attachment lies too far back in the intestine (in the cecum) for a lethal dose of these drugs to reach it. Tartar emetic is effective in treating schistosomiasis but only partially so in infections with clonorchiasis, since the drug, while probably equally lethal for both species of worms, reaches the blood flukes in the portal vessels in lethal amounts but has difficulty in penetrating through to the flukes walled off in the distal extremities of the bile ducts.

The most conspicuous increase in organs or tissues of the helminths as a group is that of the reproductive system. Both the Platyhelminths and the Nemathelminths have a large part of their body-mass occupied by these organs and their products. The adult flatworms are, with few exceptions, hermaphroditic; the roundworms are almostly entirely diecious. In both groups the volume of reproductive products is enormous for the mass of the worm. The rapidity with which these products are manufactured is equally astounding. The description of important types of reproductive organs will be found under the sections in the text dealing with the respective groups of helminths.

The adult flukes and tapeworms have particularly complex reproductive organs, directed toward one end, *i. e.*, the production of as many eggs as possible with the fewest opportunities for mishap to these reproductive products. To this end, in both groups, cross-fertilization, which was formerly the rule and is still a possibility, has been mostly superseded by self-fertilization. In the tapeworms, instead of a single body unit there are multiple segments or proglottids, each one sexually complete in itself. Thus a single worm may produce fertilized ova numbering into the thousands daily. While all of the parasitic roundworms of man, with the possible exception of *Strongyloides*, require a male attendant upon the female for the production of viable ova, the life cycles of the members of this group are, as a rule, somewhat less complicated than those of the flatworms, so that to them this requirement is not a serious handicap. In certain cases, however, infection with a single sex produces complications for the diagnostician. The unfertilized eggs of *Ascaris*, frequently indicative of infection with females only, are very

different in appearance from the fertilized ones. Infections with only male worms of these and other species cannot be diagnosed by the recovery of eggs in the feces, so that diagnosis must be made in less direct ways such as subjective symptoms. While a single male hookworm has no clinical significance (and it is highly improbable that any considerable number of males would be present in an infection without at least one female being in the group), infection with a single male *Ascaris* frequently produces sufficient digestive and reflex symptoms, particularly among small children, to justify therapeutic procedure.

Although the majority of parasitic roundworms have no reproductive stage outside of the host in which the adult worms reside, *Strongyloides* usually has a free-living generation alternating with the parasitic one. The majority of the tapeworms likewise have no reproductive cycle outside of their final host. *Cœnurus*, *Echinococcus* and *Sparganum* larvæ are exceptions to this rule. These species are all of special clinical importance, since the larval stage of each of these species is known to parasitize man.

In all of the trematode parasites of higher animals, there are always two reproductive generations outside the definitive host. These both occur in the molluscan host and are unisexually produced. Thus in *Schistosoma japonicum* infections, where each female worm lays several hundred eggs per day, it is probable that the larva from each viable egg, after hatching and penetrating the tissues of the appropriate snail, gives rise by a twofold unisexual propagation to 10,000 progeny, capable of infecting the human host. Unlike bacteria, however, the adult helminths, once arrived in their final host, do not multiply within that host, although in certain helminth infections the eggs, when laid and extruded into the tissues, are undoubtedly more pathogenic than the worms themselves.

Two systems of organs, the nervous system and the excretory system, the former in all parasitic helminths and the latter in the case of the flatworms, have been little altered in the adaptation of the organism to a parasitic existence. They are, therefore, of little significance to the clinician, but to the medical zoölogist they are very useful in showing the relationship of species, genera and even families one to the other. The arrangement of the excretory system, which has been found to be identical in the cercarial larva of the three human schistosome species, is an admirable illustration of this fact.

Viewing the group of parasitic helminths as a whole with respect to the succesive stages of adaptation which they have undergone and are undergoing, and, as a result, on the one hand, the specialization of the organs for resistance, attachment, and reproduction, and, on the other hand, the reduction in the organs of locomotion

and alimentation, one is able to appreciate how vast and how profound have been the alteration from a free-living existence and how dependent the parasite is upon the host, when once it has become so adapted.

Because parasitism is so wasteful in the production of reproductive cells that never reach the next host, particularly where two or more hosts are intercalated in the same life history, the layman may rightly wonder that the life cycles are completed at all. Yet under suitable conditions the parasite multiplies so enormously and produces such ravages in its hosts that eradication or control of the infection can only be effected by the most strenuous measures administered by public health officials who have a thorough understanding of the life cycle of the parasite and of the relationship of each phase of this life cycle to the problem in hand.

CHAPTER II.

THE INTER-RELATION OF THE HELMINTH PARASITE AND ITS HOST.

PARASITE AND HOST ADAPTATIONS.

THE host as the organism which houses and provides food for the helminth is a *sine qua non* for the latter's existence. No matter how much of its life cycle is of a free-living character, the remaining part which necessitates a host is of tremendous importance both to the parasite and to the host. To the parasite this means first of all the immediate presence of the particular host to which the parasite has become adapted. Furthermore, it involves the ability of the helminth to secure entry into the host through the proper channel, and, finally, after reaching the appropriate residence in the host, to secure nourishment without endangering the life of the host and hence its own security. To the host this means the physical burden of the helminth's presence in the body, the frequent injury of its tissues due to migration of the parasite or abrasive action of its hooks, spines, or other organs of attachment and penetration, and, what is even more serious, the toxic effect of the products secreted or excreted by the parasite and absorbed into the tissues of the host.

The adaptation of the helminth to certain particular species of hosts is a condition that has gradually developed over a long period of years. It has undoubtedly come about from the continual coexistence of the helminth and a particular species of host in the same habitat, assuring the helminth the constant hospitality of such a species under ordinary conditions. The presence of the host in a particular habitat depends on many external factors, among which may be mentioned the general climatic conditions, including temperature and moisture, local or edaphic factors, and the general distribution of that particular species of host over the surface of the globe and its ability to withstand climatic and edaphic changes. The presence of the parasite in the same habitat is largely fortuitous, depending in many cases on the movements and specialized habits of the previous host which carried the parasite about and deposited it for a longer or shorter period of free existence before it was obliged to seek entry into another host. In the case of many helminth parasites, entrance into the appropriate host is also largely fortuitous. Such instances usually depend on the host ingesting the appropriate stage of the helminth along with food or drink.

This is true for *Ascaris*, *Trichocephalus* and other nematodes which require only one host, the egg of the worms gaining access to the host as a contamination of the host's food. Such is also the ordinary method by which many tapeworms gain entry into their respective hosts. Where two or more alternate hosts are required the eggs are usually swallowed with the food of the larval host, the larval host with its parasitic progeny later becoming the food of the final host or second larval host, as the case may be. Such is the method by which the human flukes, *Clonorchis*, and *Fasciolopsis*, gain entrance to their human hosts, namely, after encystment of the larvæ in or on food consumed by man. However, other species of helminths, including certain nematodes and all of the blood flukes parasitic in man, gain access to at least one of their hosts in an active way. In the case of the hookworm and of the blood fluke, human infection results from the activity of the mature free-living larval form, once it has come in contact with the human skin, in penetrating through the layers of the skin into the softer tissues of the body, whence it continues its migration, actively (in the case of the hookworm) or passively (in the case of the blood fluke) to the seat of its adult residence in the body. This type of invasion is probably a tactic reaction, being an attempt to avoid desiccation. Furthermore, the miracidium, which hatches from the trematode egg, and the cercaria or tailed larva which emerges from the molluscan host after the parthenogenetic phases of the life cycle of the trematode have been completed, are both free-swimming organisms and were originally, at least, active invaders of the hosts which they next utilized. This type of penetration requires a selection of the proper host. At first the parasite probably attempted to attack at random all objects in its immediate vicinity, but later became adapted to a particular species of organism, which it was able to select by becoming adjusted to a particular tactic stimulus. At least two types of flukes, *Clonorchis* and *Dicrocœlium*, the miracidia of which are provided with a ciliated epithelium and organs for penetrating host tissue, have lost their use of this free-living phase of the life cycle, since their eggs never hatch naturally until they are ingested by particular species of molluscs. In both the miracidial and the cercarial stages of digenetic trematodes there are cephalic glands, with openings around the oral end of the larva, which secrete a histolytic substance helpful in dissolving the tissues of the host through which a path of migration is opened.

Once the helminth has reached its residence in the host its primary concern is to secure nourishment. For this purpose it has usually chosen a position where digested or semi-digested food is abundantly supplied. Adult worms living free in the digestive tract of the host may wander back and forth as they require. Others which are attached more or less securely to the intestinal wall may release

their hold and secure a more favorable one further along. Thus in heavy hookworm infections one finds numerous petechial hemorrhages and minute ulcers in the wall of the ileum, which signify abandoned feeding-grounds. In *Metagonimus* infection the adult worm has the ability to release its hold and obtain a new one in the intestinal mucosa, the latter being always progressively further down the gut. *Clonorchis* does not leave the bile tracts once it has migrated into them, but it may wander about in the bile capillaries. If this worm is expelled into the intestine it is usually digested at once. The blood flukes are confined to the mesenteric portal system, except that they may occasionally escape into the vena cava *via* the median and superior hemorrhoidal vessels. Their eggs escape into the lumen of the intestine (*Schistosoma mansoni, S. japonicum*) or into the bladder (*S. hæmatobium*) by rupture of the venules into which they have been forced. *Wuchereria* (*Filaria*) *bancrofti* is locked in a particular lymph channel, but the microfilariæ are free to wander through the circulation. *Fuellebornius* (*e. g.*, *Dracunculus*) *medinensis* lives in the subcutaneous tissues of man but the female worm, stimulated when she is gravid with embryos, emerges to the surface and deposits her larvæ in the water when the host washes the infected member of his body in a pool or ditch, thus providing an opportunity for the larvæ to reach the alternate crustacean host which lives in the water.

An adaptation which is optimum for the parasite requires that the host be not overburdened by the presence of the parasite nor that its life be endangered. Where the parasite has reached an equilibrium with its host, there are no clinical symptoms of disease. On the other hand, parasites which may be temporary residents in a host but cannot readily become adjusted to permanent residence, as, for example, the human *Strongyloides* in the dog, and other forms which have even less adjustment, such as the dog hookworm, *Ancylostoma caninum*, in man, and the human hookworm, *A. duodenale*, in the dog, are also of little clinical interest. In a somewhat different category is the case of the human and pig *Ascaris*, and possibly the dwarf tapeworm of man and the rat, which are morphologically indistinguishable but which apparently have specific physiological adaptations for their respective hosts. Between the perfectly adapted parasites on the one hand and the entirely non-adapted ones on the other there is a wide range of illy-adapted species, whose relationship to the host produces a reaction of the tissues which the pathologist and the clinician look upon as disease.

In certain cases a single worm, which has the ability to grow to a considerable size, giving off by-products highly toxic to the host, is sufficient to produce a pathological condition. Thus a single *Diphyllobothrium* (*Dibothriocephalus*) *latum* frequently causes severe

secondary anemia. Again, a single worm may obstruct a channel through which body fluids pass and bring about morbid reaction of the host. Such, for example, is the case when a filarial worm obstructs a lymph channel or an *Ascaris* blocks the common duct. Some worms, like the hydatid cyst, may grow to such size that they press upon contiguous organs and bring about malfunction. In other species of helminths (*Schistosoma*) the eggs of the worm extruded into the surrounding tissues produce a diseased condition much more profound than do the adult worms. Some worms in small numbers (*Clonorchis, Trichocephalus, Necator*) produce very mild reactions on the part of their host, while in large numbers they are of clinical significance. Some worms are significant in childhood and apparently decrease in their pathogenicity as the host matures. In one species at least (*Hymenolepis nana*) the worm lives almost exclusively in children, and is much less common in adults.

While all members of the human species appear to be equally susceptible to infection with helminth parasites, races of man which have been long subjected to these infections appear to be more adapted to the parasites involved than those in which the infection is relatively new. Thus the negro is less seriously affected by hookworm infestation than the Anglo-Saxon, the Chinese child appears to be less disturbed by the presence of *Ascaris* in the bowel than does the Caucasian, and a single infection of schistosomiasis assumes a mild chronic form in the native population of endemic areas more commonly than in the foreigner.

Enough has been said in the foregoing paragraphs to explain how the parasite has become associated with certain hosts and how the general process of adaptation is going on; how, in some cases a nearly perfect adaptation has been effected; how, in others, there is still no true adaptation at all; while in a very large series of cases poor adaptations exist, resulting in disease. In a broad biological sense, given contact of a host species with a pathogenic helminth for thousands of years, changes resulting in the equilibrium of the host and the parasite, with a corresponding reduction in pathogenicity, might be expected, and this undoubtedly has been the case.

TYPES OF HOSTS IN RELATION TO VARIOUS STAGES IN THE LIFE CYCLE OF HELMINTHS.

Considering the host-parasite relationship from a different viewpoint, certain terms which define this relationship occupied by the host in the life cycle of the organism have come to be accepted through common usage. This phase of the problem has both a biological and an epidemiological bearing. The host in which the adult hermaphroditic or diecious helminth develops is referred to

as the *definitive host.* This stage of the parasite has of recent years come to be known as the *marita,* or the one in which the sexual products have been fully elaborated. Thus the large intestinal fluke, *Fasciolopsis buski,* the blood fluke, *Schistosoma japonicum,* the adult beef tapeworm and the adult hookworm are all maritæ, while a man infected with these helminths is their definitive host. If another organism serves as a reservoir of such an infection and preserves the continuity of the life cycle of the parasite when man escapes infection, this host organism is known as a *reservoir host.* In endemic areas the pig frequently serves as a reservoir host for *Fasciolopsis,* and the dog for *Schistosoma japonicum,* while no reservoir host is known for either the beef tapeworm or the human *Strongyloides.* On the other hand, both the dog and the cat are reservoir hosts of *Ancylostoma braziliense,* an occasional hookworm parasite of man. In *Trichostrongylus, Triodontophorus, Gnathostoma, Gastrodiscoides* and *Fasciola* infections domestic or wild mammals are the common reservoir of infection and man is only an *incidental host.* Human infection with *Gnathostoma* usually differs from that of the common reservoir hosts, the dog, cat (*G. spinigerum*) and pig (*G. hispidum*), since in man the parasite is usually found as an immature worm in the subcutaneous tissues, while in the more perfectly adapted hosts the worm matures in gastric tumors.

In some helminth parasites the definitive host is the only one utilized. In the case of *Ascaris* and the hookworm a larval migration period through the body tissues is commonly required before the parasite settles down and grows to adulthood. In such instances, however, man cannot be referred to as a true larval host. Such a host, spoken of as an *intermediate host,* is one alternating with the definitive host in the life cycle of the parasite. Thus the ox is the intermediate host of the beef tapeworm, the mosquito is the intermediate host of Bancroft's filaria, and the mollusc that of the blood fluke. In echinococcus infection the dog is the definitive host in which the adult worm lives, and man, the ox, the sheep and the pig are the usual intermediate hosts in which the larval stage, the hydatid cyst, develops. In the case of *Trichinella spiralis,* the rat, the hog and man may serve both as definitive and intermediate hosts. The adult worms develop in the intestine (definitive stage) and the females discharge their larvæ into the blood or lymph spaces, from which they migrate to the muscle layers and encyst (larval or intermediate stage). The infected flesh when eaten by the next member of the series produces the definitive stage again, and thus the cycle is carried on.

The mollusc is an obligatory intermediate host of all digenetic trematodes. The parasitic progeny developing within the mollusc (two or more unisexual stages) are referred to as *parthenitæ.* After the cercaria emerges from the mollusc and discards its tail

it is spoken of as the *metacercaria* or *adolescaria*. The latter term is the more inclusive one, since it applies to the entire subsequent period of the fluke up to the adult stage (marita). Except for the blood flukes all of the human trematodes have a period of rest or incubation following development in the mollusc and previous to entry into the final host. If this involves a second larval host, as in *Clonorchis* infection, where a fresh-water fish is utilized, the mollusc is designated as the *first intermediate host* and the fish is known as the *second intermediate host*. In *Fasciola*- *Fasciolopsis*- and probably in the human amphistome infections the cercaria encysts on grass or other vegetable surfaces and is passively transferred to the human or reservoir host. Such a condition differs from that of encystment in the flesh of a fish, since in the fish an actual incubation or growth occurs, while the former is only a vehicle for the transfer to the definitive host. Vegetable tissue which serves such a function is, therefore, not a true intermediate host but a mechanical transfer agent or *vector*. In a broader sense flies may serve as vectors for helminth ova.

THE HELMINTH IN RELATION TO DISEASES OF ITS HOST.

Although the term "*carrier*," that is, an organism which shows no clinical symptoms of an infection, has come into use in connection with bacterial and protozoan infections, its use is still somewhat new in helminthology. There is no reason, however, why it cannot be applied equally well in human helminth infections, such as ascariasis, trichocephaliasis, ancylostomiasis, enterobiiasis (oxyuriasis) and hymenolepiasis nana, in which no intermediate host is required and in which an infected human being, manifesting no clinical symptoms, is a danger to the members of his community. In a less direct sense reservoir hosts which are infected with helminths requiring an alternate host are also "carriers."

Helminth diseases may become epidemic in nature, due to the introduction into an area of a particularly heavy infection, or to unusually favorable climatic conditions. More often, however, such diseases are endemic, the infection being maintained in a locality by a repetition of conditions or a correlation between parasites and hosts in such a way as to preserve the infection. Wherever such circumstances supervene a *vicious cycle* is established. No better example of a complicated life cycle of this kind need be found than that of *Diphyllobothrium latum*, the broad fish tapeworm, which requires *Cyclops*, fresh-water fish and man as hosts. This infection, which is so common in the lake regions of Central, Northern and Eastern Europe, has within the last half century been introduced into North America by infected emigrants from these European countries, who settled in regions in the New World where

bodies of fresh water have afforded an opportunity for the cladoceran and piscine hosts of these previously uninfected waters to become successfully infected from contamination with infected human excreta. Consumption of the uncooked infected fish served to complete the life cycle and establish the infection in the new locality.

Health officials looking toward the control of helminth infections should first discover what phase in the life cycle of the parasite is most likely to prove amenable to practical measures of prevention and then, if possible, attack the infection at that point. Since prevention of parasitic diseases is much simpler than attempts to cure, once the life cycle of the causative organism has been elucidated, the methods by which a particular helminth gains access to the human body should be closely studied and then suitable measures taken by education and by the erection of barriers so that exposure will be minimized. Meanwhile infected cases should be treated whenever specific therapeusis is known, in order to reduce the amount of infection in endemic regions and to prevent introduction of the disease into uninfected areas. Where there are important reservoirs of infections these, too, should be studied with a view of reducing the amount of infection among them. Furthermore, careful attention should be paid to the life cycle of the parasite with reference to whether it has a multiplicative period outside the definitive host. Under such conditions it is essential, if possible, to attack infection before such increase of the progeny takes place. Finally, care should be taken to erect barriers to prevent the exportation of the infection outside of the original endemic area.

CHAPTER III.

THE FOUNDATIONS OF HELMINTHOLOGY.

THE ANTIQUITY OF HUMAN HELMINTH PARASITES.

Although parasitism in the Animal Kingdom has undoubtedly been a relatively recent event when compared with the main lines of development of free-living groups of organisms, it was unquestionably well established long before the dawn of human history, and while the distribution of various species of parasites may have been considerably altered within historic times by the migration of the races, it is reasonably certain that all of the common species of human parasites are far older than the human race itself. The evidence for such belief is necessarily *a priori* but nevertheless convincing. In the first place many of the animal parasites of man are also common infections of other mammals; in many instances man is only incidentally infected. In the second place certain infections which are apparently non-pathogenic for other animals cause severe symptoms in man, thus giving evidence of a shorter period for adaptation in the human species. Furthermore, many of the parasitic forms which now require two or more hosts, including man, in which to complete their life cycles, may have originally only utilized one, the present larval host. Finally, physiological differences among parasitic species in man and other mammals, where morphological structures appear to be identical, indicate that the parasite has become established in the human kind sufficiently long to have acquired a relatively fixed adaptation.

Referring particularly to the human helminth parasites, certain species which require a period of development outside of the human body probably adapted themselves slowly from a free-living to a parasitic existence. This latter point is well illustrated in the instance of several nematode parasites infecting man. *Strongyloides,* which can probably live indefinitely outside the body, is undoubtedly a recent human parasite. The hookworm, which exists for the period of its larval development as a free-living organism, presumably has a longer history as a parasitic organism, while *Ascaris,* and to an even greater extent, *Trichocephalus* and *Enterobius,* show evidence of long-continued existence as essentially parasitic species. The helminth parasites of the blood and lymph channels have undergone more profound adaptations, particularly of a physiological character, than those of the digestive tract or

its outpocketings, suggesting that the former are possibly far the older.

Thus essentially all of the helminth parasites of man of the present time must have been human infections a hundred thousand years ago, while other infections now found almost exclusively in domestic mammals but potentially parasites of man, must have also been man's portion. The hunter of wild oxen and wild boars became infected with tapeworms, *Ascaris* and *Trichinella*. The primitive fisherman incurred with his consumption of raw fish, fish tapeworm (*Diphyllobothrium*) and liver-fluke infections. The herdsman, mingling with his sheep and his dogs, incurred hydatid disease. As he drank from an oasis pool, where a previous traveller had bathed, he subjected himself to dracunculus infection. Insects stung his unprotected body and in so doing conveyed filarial infections to him. As he began to settle down and till the soil he came more and more in contact with others of his own species and race, so that unhygienic conditions developed from the accumulation of infected human excreta, with the result that hookworm disease and infections with *Strongyloides*, *Ascaris* and *Trichocephalus* became endemic. In the Nile and in the Yangtze valleys fishermen and farmers wading about in the irrigation canals incurred schistosomiasis. The rat conveyed *Hymenolepis* infection and the dog flea, *Dipylidium* infection. So it was that at the dawn of history foyers of helminth infection were distributed throughout the entire habitable world.

KNOWLEDGE OF HELMINTH DISEASES BY ANCIENT PEOPLES.

The annals of the Accadian peoples refer to *Ascaris* and tapeworm. The Ebers Papyrus (16th century B.C.) is the oldest record in which a helminth is regarded as a pathogenic organism, the diseases "A A A" and "U H A" being attributed to a worm ("Heltu"). Although it is impossible to say whether the worm referred to is an *Ascaris*, a hookworm, a tapeworm or some other helminth, it is interesting that symptoms were attributed to the presence of this "bowel worm" and that a remedy was prescribed for its expulsion. The use of Quisqualis seeds by the Chinese as a mild vermifuge also dates back into early historical records. Egyptian mummies have furnished evidence of the existence of *Schistosoma hæmatobium*, the causative organism of vesical bilharziasis in the Nile delta during the 13th century B.C.

The Hebrews were instructed in the laws of sanitation and hygiene by Moses, who had secured his learning from the Egyptian priests. The "fiery serpent" in the wilderness of Sinai was no other than the Medina or Guinea worm, *Fuellebornius* (*Dracunculus*)

medinensis, and the likeness which Moses made by winding the "serpent" around a rod (Numbers 21 : 5–9) served as an example for the people in extracting the worm from their tissues by winding it around a stick, the simple but satisfactory method employed by Arabs and Africans in infected areas today. Moses likewise separated the animals into "clean" and "unclean" on the basis of those free from or infected with visible parasites. This was particularly true of goats and kids, first offered for sacrifice and latter eaten by the priests. Goats in Syria today are heavily infected with *Fasciola hepatica,* and the people eating the infected raw livers acquire "halzoön" or pharyngeal fascioliasis. All scavenger beasts and birds were prohibited from use as food, including hogs and camels, birds of prey, reptiles, snails, etc., because their flesh was infested with parasites (Lev. 11). Likewise all animals not on the prohibited list, whose flesh was found infested, were required to be burned (1490–1450 B.C.). Furthermore, Moses advised the people to beware of "infected water," which, no doubt, at that time, as today, contained *Cyclops,* infected with the larvæ of the Guinea worm, as well as the free-swimming cercariæ of *Schistosoma hæmatobium.* Later the Hebrews were instructed in the method of drinking water from their hands rather than lapping it up directly from a stream, possibly so as to avoid swallowing blood-sucking leeches (Gideon's army, *vide* Judges 7 : 5–7).

Aristotle mentions tapeworms. Echinococcosis was diagnosed by the Greek physician Hippocrates.

The most ancient medical record in the Christian Era of interest to the helminthologist is that of Avicenna, an Arab physician, who was born in 981 A.D. and died in 1037 A.D. He described four kinds of worms: (1) Long worms, apparently *Ascaris lumbricoides,* found in the small intestine, not malignant, but causing loss of appetite, sleepiness, distention of the abdomen and diarrhea, and for which santonin seed was recommended as specific; (2) flatworms, pumpkin-seed-shaped, probably *Tænia saginata,* acquired from eating raw beef, a custom common among butchers in the slaughter houses of Cairo today, often found in the small intestine, but also occurring in the rectum and often migrating out of the anus, causing a "malignant" disease, but seldom found during infancy; for them a very potent anthelminthic, *filix mas,* was recommended; (3) small worms, probably *Enterobius* (*Oxyuris*) *vermicularis,* common in the cecum and colon, often migrating out of the anus, causing little harm, but producing discomfort in the form of itching around the buttocks; for them enemata with salt water were recommended; (4) roundworms, probably the hookworm, *Ancylostoma duodenale,* found in the small intestine, more frequent in boyhood and early maturity than in old age, producing "malignant" symptoms, such as excessive appetite, flatulence, anasarca, palpitation and epilepsy, obstruction and per-

foration of the bowel; they were difficult to expel, although *filix mas*, tar and aloes were mentioned as useful in expelling them.

The early Arabian physicians also correlated elephantiasis with the presence of a filarial worm.

THE BEGINNING AND DEVELOPMENT OF MODERN HELMINTHOLOGY.

The first trematode or fluke to be recognized was *Fasciola hepatica*, the causative organism of sheep liver rot, discovered by Jehan de Brie in 1379, and more accurately described by Gabucinus in 1547. The names of Leeuwenhoek (1675), Swammerdam (1752), Rosenhof (1758), O. F. Müller (1777), Goeze (1787, 1800) and Zeder (1800) are all linked up with observations on trematode species, principally of a descriptive nature. At first these worms were referred to as "sucking worms" and were confused with the leeches. In 1808 Rudolphi gave the group the name "Trematoda," from *τρηματώδα* or "body pierced with holes." For the next three-quarters of a century Mehlis (1831), v. Nordmann (1832), v. Siebold (1835), Steenstrup (1842), de Filippi (1857), La Valette St. George (1855), Pagenstecher (1857) and others were laying foundation-stones leading up to the epochal discovery by Leuckart (1883) and by Thomas (1883) of the complete life history of the sheep liver fluke, involving an alternation of generations and requiring a snail as an intermediate host. Meanwhile Busk (1843) had discovered the giant intestinal fluke, *Fasciolopsis buski*, and Bilharz (1851), the human blood fluke, *Schistosoma hæmatobium*, and the small intestinal fluke, *Heterophyes heterophyes*. There followed the finding of *Clonorchis sinensis* by McConnell in 1874, of *Paragonimus* by Kerbert in 1878 and Ringer in 1879, of *Schistosoma japonicum* by Katsurada in 1904, and the differentiation of *Schistosoma mansoni* from *S. hæmatobium* by Sambon in 1907. The elucidation of the life cycles of all of these human infections has come within the last two decades. First and most important was that of *Schistosoma japonicum*, the causative organism of Oriental schistosomiasis, which had been recognized by the Japanese as a disease entity since 1847. Starting with the classical work of Fujinami (1909) who showed that water from irrigation ditches in endemic areas was the source of infection, various Japanese investigators, including Miyagawa (1912) and Miyairi and Suzuki (1913) first traced the route of invasion of the parasite through the mammalian body from the skin to the mesenteric veins, and later demonstrated the rôle of the amphibious snail, *Katayama nosophora*, as intermediate host in the infection. Later Faust and Meleney (1924) found that the related mollusc, *Oncomelania hupensis*, as well as *K. nosophora*, were

responsible for the infection in China, where approximately 100,000,000 persons were yearly exposed to the infection. In 1915 Leiper worked out the life cycles of *Schistosoma hæmatobium* and *S. mansoni,* showing that these blood flukes also required a snail for their intermediate stages and proving conclusively that they were separate species. There followed the experiments of Nakagawa (1915–1919), Ando (1917), Yoshida (1916), Kobayashi (1918–1921) and Yokogawa (1919) on *Paragonimus,* in which these investigators found not only molluscs but fresh-water crabs and crayfish involved; the investigations of Yokogawa and others on *Metagonimus,* in which both molluscs and fresh-water fishes were incriminated; the work of Nakagawa (1921) and Barlow (1925) on *Fasciolopsis buski,* demonstrating that the life cycle of this fluke followed closely that of *Fasciola hepatica* and that water nuts were the agents of human infection; and, finally, the extensive studies of Kobayashi (1910–1917), Muto (1918), Nagano (1925–1926) and Faust and Khaw (1924–1927) on *Clonorchis sinensis,* demonstrating that this infection required as a first intermediate host a bithynoid snail and later, as second intermediate hosts, fresh-water fishes, consumption of which in the raw state brought about the infection; and that practically all of the fresh-water fishes in the Sino-Japanese areas were naturally infected with the encysted larvæ of this fluke.

As has been stated previously, tapeworms were known to the Greeks. In 1592 *Tænia* was distinguished from *Diphyllobothrium* (*Dibothriocephalus*). Redi (1687–1695) recognized the larval stage of *Tænia,* the cysticercus, as an animal form. Not until 1851, however, did Küchenmeister prove by feeding experiments that these bladder worms represented the alternate or immature phase of the life cycle of the tapeworm and that, as a rule, they required a different host from that of the adult worm. The life history of the pork tapeworm, *Tænia solium,* was first worked out by Küchenmeister (1855) and Leuckart (1856). The investigations of Leuckart (1861), Mosler (1863), Oliver (1869) and Perroncito (1876–1877) proved that the beef tapeworm, *Tænia saginata,* required a similar alternation of larval and adult hosts. Von Siebold (1853), Küchenmeister (1861), Leuckart (1862) and Naunyn (1863) elucidated the life history of the hydatid worm, *Echinococcus granulosus.* The dwarf tapeworm of man, *Hymenolepis nana,* first discovered by Bilharz in Cairo (1851), was believed by Grassi (1887) and others to be the same species as that found in the mouse. In 1920 Joyeux proved that in the case of this tapeworm no intermediate host was required, since both the larval and adult forms grew in the same experimental mammal, while Saeki in the same year showed by human feeding experiments that the human and mouse species were probably identical. Braun (1883), Parona (1886), Grassi (1886), Ijima (1888) and Zschokke (1890) showed that infection with the fish tapeworm, *Diphyllobothrium* (*Dibothriocephalus*) *latum,* was

contracted through consumption of fresh-water fish. It remained, however, for Rosen and Janicki (1917, 1918) to demonstrate the complete life cycle of this parasite, which was found to pass its first larval stage in small copepods, *Cyclops* and *Diaptomus*, before its passive entry into the fish along with the first larval host. Following this discovery Okumura (1919) showed that Manson's tapeworm, *Diphyllobothrium mansoni*, also utilized *Cyclops* as a first intermediate host, but that frogs and snakes served as the second intermediate hosts, conveying the infection to mammals.

Four of the nematodes parasitic in man, *Ascaris lumbricoides*, *Enterobius* (*Oxyuris*) *vermicularis*, *Trichocephalus trichiurus* and *Fuellebornius* (*Dracunculus*) *medinensis*, were listed by Linnæus in his Systema Naturæ (1758–1767), while Gmelin recorded *Metastrongylus apri* in 1789 and Rudolphi described *Hæmonchus contortus* in 1803. In 1843 Dubini first described the hookworm, discovered by him in 1838 at the autopsy of a Milanese woman. In 1846 Leidy discovered *Trichinella spiralis* in pork, the first record of its presence in other than the human subject. Bancroft (1876–1877) first recovered the adult filarial worm, *Wuchereria* (*Filaria*) *bancrofti*, from lymph abscess of an arm and from hydrocele fluid of patients in Brisbane, Australia, although the microfilarial larvæ of this species had been known for several years.

Sir Patrick Manson made the first epochal life-history contribution to the nematode group, by demonstrating (1878–1879) that the mosquito served as the larval host of Bancroft's filaria, and that the periodicity of the microfilariæ of this species in the peripheral blood of man appeared to be related to the life cycle. Fedschenko (1869) showed that *Cyclops* was probably the intermediate host of *Fuellebornius* (*Dracunculus*) *medinensis*, a view later verified by Manson (1894) and by Leiper (1907). Leuckart (1882) proved that the parasitic and free-living generations of *Strongyloides*, namely *S. intestinalis* and *S. stercoralis* were part of the same life cycle. In 1881 Perroncito published his findings on the development of the free-living larvæ (rhabditiform and filariform stages) of the hookworm, while Leichtenstern (1886–1887) claimed that the mature larva was capable of developing into the adult worm in the human intestinal tract. Complete demonstration of the life cycle of the hookworm was effected by Looss (1896–1897), who showed that the mature filariform larva was the infective stage for man, that the usual portal of entry was through the skin, and that an indirect route through the venous circulation to the lungs, thence out into the air passages, and over the epiglottis into the digestive tract, was required before the young worms attached themselves to the wall of the intestine and matured. In 1902 Stiles showed that the hookworm common in man in the Western Hemisphere was different from that of the Old World species, and in 1903 gave it the name *Necator americanus*. Recent work by

Fülleborn and by Yokogawa (1925) and other Japanese investigators has further elucidated the life cycle of the hookworm. Davaine (1863) first observed that *Ascaris* larvæ hatched from eggs fed to experimental rats. Lutz (1888) and Epstein (1892) demonstrated that the swallowing of the mature embryonated egg of *Ascaris* resulted in the development of mature worms. In 1916 Stewart showed that the immature *Ascaris* larva, which hatches from the embryonated egg introduced into the digestive tract, migrates through the tissues before it is able to mature in the intestinal lumen. Ransom and his colleagues (1920–1921) and Yokogawa (1923) not only verified this work of Stewart but also conclusively demonstrated that only one host is required for *Ascaris*. Moreover, Ransom and Cram proved that these larvæ utilized the portal veins or the lymphatics *en route* from the intestines to the lungs.

THE MODERN TREND IN HELMINTHOLOGY.

During the last decade epidemiological studies on hookworm disease, looking toward its eradication, have been undertaken on an extensive scale by various agencies, particularly the Division of International Health of the Rockefeller Foundation coöperating with various governments. These investigations have included studies throughout the tropics and subtropics on the incidence of the infection in individuals and in populations; refined methods of technique in determining the degree of infections in individuals (worm-count, brine floatation, and egg-count) and the amount of infestation in the soil (Baermann technique); improved therapeusis (*e. g.*, administration of carbon tetrachloride, and later of carbontetrachloride-chenopodium-mixtures, on a large scale), as well as the application of treatment to large groups (mass therapy); and finally on the biology of hookworm disease in the field (Cort and his colleagues, 1921-1926).

Thus the first steps in the scientific study of the helminth groups consisted in the description and classification of species. Later the subject of comparative morphology and relationships occupied the attention of investigators. With these more elementary but essential facts as a foundation, life-history data were then accumulated. While much remains to be done in each of these lines of investigation, the more pressing problems for the future involve the practical application of the information recently acquired, namely the relative pathogenicity of various species of human helminths, the number of individuals required for a clinical infestation, improved methods of detecting the presence of helminths, particularly during the period of incubation, improved therapeusis, and, what is more important, the application of biological and epidemiological data to the erection of barriers, looking toward the control and eradication of these infections.

CHAPTER IV.

THE NOSOGEOGRAPHY OF HELMINTHIC INFECTIONS.

GENERAL CONSIDERATIONS.

In contrast to the immediate environmental factors to which the helminth has become adapted as a parasite and on which, to a very great extent, it is constantly dependent, is the distribution of the organism over the surface of the globe or its *nosogeographic range.* Until recent years it was commonly believed that human helminth infections were confined almost exclusively to the tropics and information concerning them was confined for the most part to treatises on tropical medicine. However, epidemiological studies on a large scale have shown, that, although the tropics are perhaps the most favorable regions for the propagation of parasitic infections, many of the most important helminth parasites have a wide distribution in temperate regions and that some even extend into the frigid zones. On the other hand, there are extensive areas in the tropics which are too dry for helminths to perpetuate themselves.

The only serious helminth infection which is limited almost exclusively to the tropics and the adjacent subtropical belts is hookworm disease, which, broadly speaking, completely encircles the inhabited regions of the globe between 20° N. and 20° S. latitude. Yet even in this case there are numerous endemic foci, principally in mines, as far north as 50° N. latitude. Furthermore, it has been found that *Necator americanus* is more strictly a tropical or subtropical parasite than *Ancylostoma duodenale,* which has its optimum habitat in a somewhat cooler zone, while *Ancylostoma caninum,* the dog hookworm, flourishes in an even colder climate.

Unlike many of the vertebrates, arthropods and molluscs, the distribution of parasitic helminths is rarely coincident with faunistic areas. *Ascaris, Trichocephalus* and the majority of the human tapeworms are practically cosmopolitan in their distribution. Schistosomiasis hæmatobia and dracunculus-infection are both African and Oriental; schistosomiasis mansoni is African and Neotropical; schistosomiasis japonica is confined to the Sino-Japanese area of the Oriental region, as is also *Clonorchis* infection.

DISTRIBUTION OF HELMINTHS DEPENDENT ON THE DISTRIBUTION OF THEIR HOSTS.

A careful study of the situation shows that, in addition to climatic considerations, helminths are widespread or limited in their

distribution, depending to a very great extent on the distribution of their hosts. Thus infections requiring no host other than man and those requiring intermediate hosts usually associated with man, such as the ox, the pig, the dog, or the rat are nearly as widespread as is the human population itself, while those requiring a special type of intermediate host, such as a mollusc with limited distribution, are limited in their extent to the distribution of this particular host. Some molluscs are fairly cosmopolitan in their distribution, others are very limited in their range. Thus the widespread distribution of species of *Lymnœa* throughout the moist temperate zones is no doubt responsible for the common occurrence of *Fasciola* infection in practically all areas into which the disease has been introduced in infested sheep. On the other hand schistosomiasis japonica is adapted to a peculiar group of molluscs of limited distribution in the Sino-Japanese areas, so that its introduction into other regions is very improbable. The absence of this disease in Korea, which lies intermediately between heavy endemic areas in Japan and China, is undoubtedly due not to the lack of infected human beings in the country but rather to the absence of the particular snail and the inability of the blood fluke to adapt itself to other unrelated species of molluscs.

CLOSE DEPENDENCE ON PHYSICAL SURROUNDINGS.

In many cases the slightest deviation in the physical surroundings of a given geographical area or in the customs of the population may be responsible for an epidemic of one or another kind of helminth infection. In the time of Moses, the water supply of the Hebrews became poor in the desert of Hor, where they were encamped; they drank water from drying pools and ditches and became infected with a plague of the Medina worm, the larvæ of which some transient Arab had previously left in the pool when he stopped by the wayside to bathe his ulcerated arm or leg. In this same way the epidemic of hookworm broke out among the construction gangs who were digging the St. Gothard tunnel, where the moist earth was favorable for development of the larvæ. In this same way pork tapeworm became a pest in parts of Germany fifty years ago, because the inhabitants were fond of eating raw pork flesh. In this same way the broad fish tapeworm was introduced into the lake districts of Northern Minnesota, Michigan and lower Canada by the Scandinavian immigrants who had perpetuated in their new homes the same vicious insanitary cycle which they had been used to in Europe. And a similar single change of the topography of Lower Egypt, namely, the introduction of irrigation projects in the Nile delta, has been responsible for the spread of bilharziasis in that territory within very recent years.

Moisture is a *sine qua non* for the majority of helminth infections. Infection with *Fasciola hepatica* not only requires snails and sheep but also moist pasture land. *Clonorchis* requires snails and fish, which are in turn dependent on moisture. *Paragonimus* requires snails and crabs, which are both aquatic hosts. The schistosomes are dependent on an aquatic medium for their transfer to man as well as for the infection of their molluscan hosts. The hookworm utilizes no intermediate host but demands moisture and shaded warmth during its free-living phases. Only those forms in which the transfer from the intermediate to the definite host is direct (*i. e.*, the intermediate host is the food of the final host) and in which the definite host or its excreta immediately reaches the larval host, are independent of a continuously moist environment.

Moisture results primarily from rainfall, which in turn is dependent upon the winds, and upon the topography of the country, particularly the mountain systems near the sea. It is also dependent on the absolute temperature due to latitudinal position on the earth. Thus, on the island of Vitilevu of the Fijian group, a mountain chain prevents the rains, which the trade winds from the southeast precipitate on that side of the island, from reaching the northwest side. Ancylostomiasis on the wet side rises to 90 per cent of the native and Indian population while a similar population on the drier side has only a 38 per cent infection. Strongyloidiasis is even more limited than ancylostomiasis to warm moist regions of the globe because the free-living larvæ of the parasites are very sensitive to drought. Trichocephaliasis is also much more common in moist than in dry areas. Schistosomiasis japonica does not exist outside of those areas where the banks adjacent to the drainage canals are not continually moist.

High inland plateaus or inland areas, shut off from adjacent moist regions by mountain chains, are invariably dry and the helminth fauna of such regions is proportionally reduced, consisting among the indigenous non-migratory animals of nematode species in which the eggs are resistant to considerable desiccation and of cestode forms in which the larvæ have a direct transfer from definitive to larval host and back again to definitive host.

The monsoons of the Indian Ocean and the adjacent bodies of water, coming from the southwest and proceeding up the Arabian Sea, the Bay of Bengal and the China Sea, have a marked effect on the Asiatic Continent as far inland as the Himalayas. As one proceeds from the coast first in contact with the monsoons, where precipitation is heaviest, travelling northward and inland, he reaches territory where the rainfall is both less extensive in duration and less intensive in daily amounts. The helminth fauna of these regions is usually directly proportional to the amount of precipitation. Thus it has been found that in China hookworm infection is

not clinically important north of the Tsing Ling Range (between the Huai and Yellow Rivers), where the annual precipitation is less than 75 cm.

In countries where there is intensive dry heat in summer (up to 125° to 150° F. in the sun) and bitter cold in winter (–40° to –60° F.). such as one finds in Siberia, the conditions are most unfavorable for the growth of helminths. Where the summer climate is hot and humid, with adequate or luxuriant vegetation such as one finds in the tropics and subtropics, and where the winter climate is also warm and moist, such as is found in the Malay Archipelago and other countries where at sea level the average yearly temperature is between 75° and 85° F., optimum conditions exist for helminth development.

HYGIENE AND SANITATION IN RELATION TO HELMINTHIC INFECTIONS.

With these broader, more general conditions of the environment in mind, attention may now be directed to other external agencies which control the development and distribution of helminth infections. Among the many factors other than meteorological that govern the dissemination of helminthic infections and their incidence in man the following may be mentioned:

1. Food.
2. Drinking water.
3. Night-soil.
4. Migration and travel.

This list is not exhaustive. The factors named are not necessarily arranged in the order of their importance, nor are they separate and distinct from one another. Certain of these factors are of historical importance only. Others are known or determinable entities which may be of primary importance in the control of the infections as they now exist.

1. **Food.**—The food of a people is always an important point of attack in attempting to discover the etiology of an infection and in establishing preventive measures for its eradication. For example, the Chinese and Hindus, thoroughly cook the greater part of their food. A considerable part of this is eaten while hot. Yet some of it is allowed to stand uncovered in stalls and restaurants for a considerable time before it is consumed, during which interval it is exposed to dust and dirt, flies and domestic animals. Still other foods are eaten raw, particularly vegetables. Generally speaking foods grown in the ground, where human night-soil is used as fertilizer, are all more or less contaminated. Furthermore, in order to keep these vegetables in a fresh condition in the markets, the bazaar venders sprinkle them from time to time with brooms which have

been dipped in dirty, contaminated water. This is particularly true of such delicacies as the large Chinese radish, the water chestnut, lotus roots and bamboo shoots, all of which the Oriental enjoys eating uncooked. Lengths of sugar cane are soaked in dirty water. Oranges which have begun to wither are given a hypodermic injections of contaminated water to improve their sale. Melons and cucumbers are only less likely to be the source of helminthic infection in Oriental and tropical countries than of protozoan and bacterial contamination. For those individuals in Oriental or tropical countries who eat fresh celery and lettuce a source of contamination is ever present. In China and India the water chestnut and the red water ling are means by which *Fasciolopsis* infection is conveyed. The encysted larval fluke adheres to the skin of the corm so that in peeling off the skin with the teeth and lips some of the cysts get into the mouth and thence reach the intestine, where the cyst capsule is digested away and the larval worms grow to adult form. In other regions of China, as in Formosa, perhaps the infection is also conveyed by eating herbs or grass. It is common knowledge among the farmers of Central China where the infection occurs in hogs as well as in man, that animals kept in the courtyards do not get the infection, while those that pasture on the hillside or in the fields sooner or later contract the infection.

The Chinese people as a rule differ from their immediate neighbors around the China Sea in not eating fish or arthropods in the uncooked state. They should, therefore, be free from the common fluke diseases of the Japanese, Koreans, Formosans and Tonkinese, which are incurred through the consumption of such food, namely clonorchiasis, metagonimiasis and paragonimiasis. Recent investigations have shown that dogs and cats harbor the former two of these infections throughout the moist areas of China, while wild cats, panthers and tigers in the mountains of Fukien, Kiangsi and Hunan provinces may possibly be infested with *Paragonimus* as they are in the adjacent regions of Korea, Siam and Assam. Thus these three species of flukes are probably all potential human parasites in China as in other parts of the Sino-Japanese area. What are the facts regarding human infection? In North China locally incurred infections are unknown; in Central China they are rare; but in South China, the Cantonese and Swatowese, who eat raw fish, are heavily infected with *Clonorchis* and to a lesser extent with *Metagonimus*. Apparently the only Chinese who have become infected with *Paragonimus* are those who have lived in Japan, Korea or Formosa and have become infected in those endemic areas.

2. **Water.**—Water in all tropical and Oriental countries is always subject to suspicion, not only for drinking but also for bathing purposes. Even where there is no danger from typhoid, cholera and bacillary dysentery, the cercariæ of the human blood flukes

are found in quiet pools, canals or irrigation projects over so large a portion of Africa, the adjacent regions of Eurasia, South America and the Far East as to make bathing in such waters extremely dangerous. The incidence of bilharziasis among the Australian troops in Egypt during the World War and the common occurrence of Oriental schistosomiasis among farmers, boatmen and foreign sportsmen in the Yangtze valley are outstanding instances of such danger. Furthermore, raw drinking water in endemic areas is the source of dracontiasis and possibly of sparganosis.

3. **Night-soil.**—Without doubt the most potential source of human infection with helminths is that of night-soil. No dogmatic statement concerning the actual percentage of cases of infection which this provides can be made, since in the first place conditions of disposal of night-soil vary tremendously in various parts of the world; and in the second place almost nothing is known about the viability of eggs, cysts and larvæ in night-soil during the time it is kept and prepared for manurial purposes.

The disposal of night-soil may be divided into two categories: (*a*) that in which manurial use is made of it, and (*b*) that from which no manurial use is derived.

(*a*) China, Japan, Korea, India, Egypt and parts of France make use of human manure for fertilizer. In some of these countries night-soil is conserved in liquid form in storage vats, where in many cases the helminth ova remain viable and are dispersed when the manure is spread over the fields.

(*b*) In most Western countries and in the tropics no economic use is made of human night-soil. Moreover, in many regions, but particularly in the tropics, a great amount of infection is spread by unclean habits of defecation, by promiscuous defecation on the part of children, and by improper methods of disposal of human excreta. Country districts in Western lands are more backward in sanitation than are cities, hence hookworm and *Ascaris* infection in such regions is essentially a rural problem.

4. **Migration and Travel.**—Hookworm (*Necator americanus*) and *Schistosoma mansoni* are believed to have been introduced into the Western Hemisphere through the importation of negro slaves from the Gold Coast and Mozambique. The former required no adaptation; the latter found an appropriate intermediate host in the molluscs, *Planorbis olivaceus* and *P. guadeloupensis*. Mention has already been made (Chapter II) of the introduction and establishment of *Diphyllobothrium latum* infection by immigrants from Central and Northern Europe into North America. Darling has shown how the Punjabis and Chinese immigrants to Malaya and Micronesia have altered the hookworm index of these countries by the introduction of *Ancylostoma*, while European immigrants to Brazil have superimposed *Ancylostoma* infection upon that of

Necator. Chinese returning from the Malay States and the South Seas have introduced *Necator* into South and Central China while travel between these regions and North China is even now carrying it temporarily beyond its optimum temperature range. Wherever the Mohammedan religion has spread, *Tænia solium* has ceased to become an important disease but *Tænia saginata* has become endemic.

However, migration and travel cannot be held entirely responsible for the apparently greater distribution of helminth infections today than the known distribution a quarter of a century ago. Much is due to our more adequate knowledge of the subject, particularly to surveys and investigations within recent years. Thus van Beneden, writing in 1889, stated that the broad tapeworm occurred only in Russia, Poland and Switzerland; that *Hymenolepis nana* has been observed nowhere except in Abyssinia: that *Ancylostoma* was known only in the south of Europe and the North of Africa; that the dracunculus was believed to occur only in the east and west of Africa; and that "the Bilharzia, that terrible worm, had only been found in Egypt." A comparison of such data with those available at the present time for these and other helminths indicates how rapidly knowledge of the subject has developed.

Thus we find, that environmental factors, whether they are the more general conditions of climate and topography or the more specialized ones of the parasite and its host to the immediate setting, all play an important part in the propagation and dispersal of helminthic infections.

CHAPTER V.

THE SCIENTIFIC NOMENCLATURE OF HELMINTH PARASITES.

INTRODUCTION. THE INTERNATIONAL CODE OF ZOÖLOGICAL NOMENCLATURE.

Undoubtedly the most perplexing and most troublesome element entering into the study of any group of animals or plants is the terminology or nomenclature of the various species. Of animals alone it has been conservatively estimated that there are probably more than 10,000,000, of which only about one-tenth have been carefully described and named. To the medical zoölogist or the clinician, who is primarily interested in the study of a parasitic organism in relation to its environment and the disease which it occasions in its host, the application of a set of rules, which appears to be arbitrary and at the same time inconsistent, is irksome and cumbersome. As a matter of fact the rules which apply to zoölogical nomenclature may be arbitrary but they follow with the utmost consistency a code of procedure, based on the work of the physician Linnæus, and framed by a representative group of zoölogists, including a considerable number of those particularly interested in the medical aspects of the subject. The basic principle of the present-day classification is that of *binomial nomenclature,* first proposed by Linnæus in 1751 and expanded by him in the tenth edition of his "Systema Naturæ" (1758). For nearly a century and a half following Linnæus' time various individuals or groups of individuals attempted to modify or supplement this code, but without marked success. In 1889 R. Blanchard presented to the First International Zoölogical Congress in Paris an International Code which was adopted by that and the subsequent Congress (1892) but failed to receive universal sanction. At the Third Congress (1895) an international commission was appointed to develop a code which would be acceptable to all groups of zoölogists. Progress reports were made at the Fourth and Fifth Congresses and at the Sixth Congress (1904) the commission was made permanent and a sub-commission, which had been previously delegated "to edit the code in English, French and German," presented The International Code of Zoölogical Nomenclature.

This code consists of thirty-six simple articles, together with recommendations and discussion. These articles are as follows:

General Considerations.

"*Article* 1.—Zoölogical nomenclature is independent of botanical nomenclature in the sense that the name of an animal is not to be rejected simply because it is identical with the name of a plant. If, however, an organism is transferred from the vegetable to the animal kingdom its botanical names are to be accepted in zoölogical nomenclature with their original botanical status; and if an organism is transferred from the animal to the vegetable kingdom its names retain their zoölogical status.

"*Article* 2.—The scientific designation of animals is uninominal for subgenera and all higher groups, binominal for species, and trinominal for subspecies.

"*Article* 3.—The scientific names of animals must be words which are either Latin or Latinized, or considered and treated as such in case they are not of classic origin.

Family and Subfamily Names.

"*Article* 4.—The name of a family is formed by adding the ending *idæ*, the name of a subfamily by adding *inæ*, to the root of the name of its type genus.

"*Article* 5.—The name of a family or subfamily is to be changed when the name of its type genus is changed.

Generic and Subgeneric Names.

"*Article* 6.—Generic and subgeneric names are subject to the same rules and recommendations, and from a nomenclatural standpoint they are coördinate, that is, they are of the same value.

"*Article* 7.—A generic name becomes a subgeneric name, when the genus so named becomes a subgenus, and *vice versa.*

"*Article* 8.—A generic name must consist of a single word, simple or compound, written with a capital initial letter, and employed as a substantive in the nominative singular. Examples: *Canis, Perca, Ceratodus, Hymenolepis.*

"*Article* 9.—If a genus is divided into subgenera, the name of the typical subgenus must be the same as the name of the genus (see Article 25).

"*Article* 10.—When it is desired to cite the name of a subgenus, this name is to be placed in parentheses between the generic and the specific names. Example: *Vanessa* (*Pyrameis*) *cardui.*

Specific and Subspecific Names.

"*Article* 11.—Specific and subspecific names are subject to the same rules and recommendations, and from a nomenclatural standpoint they are coördinate, that is, they are of the same value.

"*Article* 12.—A specific name becomes a subspecific name when the species so named becomes a subspecies, and *vice versa.*

"*Article* 13.—While specific substantive names derived from names of persons may be written with a capital initial letter, all other specific names are to be written with a small initial letter. Examples: *Rhizostoma Cuvieri* or *Rh. cuvieri, Francolinus Lucani* or *F. lucani, Hypoderma Diana* or *H. diana, Laophonte Mohammed* or *L. mohammed, Oestrus ovis, Corvus corax.*

"*Article* 14.—Specific names are:

"(*a*) Adjectives, which must agree grammatically with the generic name. Example: *Felis marmorata.*

"(*b*) Substantives in the nominative in apposition with the generic name. Example: *Felis leo.*

"(*c*) Substantives in the genitive. Examples: *rosæ, sturionis, antillarum, galliæ, sancti-pauli, sanctæ-helenæ.*

"If the name is given as a dedication to one or several persons, the genitive is formed in accordance with the rules of Latin declination in case the name was employed and declined in Latin. Examples: *Plinii, Aristotelis, Victoris, Antonii, Elisabethæ, Petri* (given name).

"If the name is a modern patronymic, the genitive is always formed by adding, to the exact and complete name, an *i* if the person is a man, or an *æ* if the person is a woman, even if the name has a Latin form; it is placed in the plural if the dedication involves several persons of the same name. Examples: *Cuvieri, Möbiusi, Nunezi, Merianæ, Sarasinorum, Bosi* (not *bovis*), *Salmoni* (not *salmonis*).

"*Article* 15.—The use of compound proper names indicating dedication, or of compound words indicating a comparison with a simple object, does not form an exception to Article 2. In these cases the two words composing the specific name are written as one word with or without the hyphen. Examples: *sanctæ-catharinæ,* or *sanctæcatharinæ, jan-mayeni,* or *janmayeni, cornu-pastoris* or *cornupastoris, cor-anguinum* or *coranguinum, cedo-nulli* or *cedonulli.*

"Expressions like *rudis planusque* are not admissible as specific names.

"*Article* 16.—Geographic names are to be given as substantives in the genitive, or are to be placed in an adjectival form. Examples: *sanctipauli, sanctæ-helenæ, edwardiensis, diemenensis, magellanicus, burdigalensis, vindobonensis.*

"*Article* 17.—If it is desired to cite the subspecific name, such is written immediately following the specific name, without the interposition of any mark of punctuation. Example: *Rana esculenta marmorata* Hallowell, but not *Rana esculenta* (*marmorata*) or *Rana marmorata,* Hallowell.

"*Article* 18.—The notation of hybrids may be given in several ways; in all cases the name of the male parent precedes that of the female parent, with or without the sexual signs:

"(*a*) The names of the two parents are united by the sign of multiplication (×). Example: *Capra hircus* ♂ × *Ovis aries* ♀ and *Capra hircus* × *Ovis aries* are equally good formulæ.

"(*b*) Hybrids may also be cited in form of a fraction, the male parent forming the numerator and the female parent the denominator. Example: $\frac{\textit{Capra hircus}}{\textit{Ovis aries}}$. This second method is in so far preferable that it permits the citation of the person who first published the hybrid form as such. Example: $\frac{\textit{Bernicla canadensis}}{\textit{Anser cygnoides}}$ Rabé.

"(*c*) The fractional form is also preferable in case one of the parents is itself a hybrid. Example: $\frac{\textit{Tetrao tetrix} \times \textit{Tetrao urogallus}}{\textit{Gallus gallus}}$ In the latter case, however, parentheses may be used. Example: (*Tetrao tetrix* × *Tetrao urogallus*) × *Gallus gallus*.

"(*d*) When the parents of the hybrid are not known as such [*parents*], the hybrid takes provisionally a specific name, the same as if it were a true species, namely, as if it were not a hybrid: but the generic name is preceded by the sign of multiplication. Example: × *Coregonus dolosus* Fatio.

Formation, Derivation and Orthography of Zoölogical Names.

"*Article* 19.—The original orthography of a name is to be preserved unless an error of transcription, a *lapsus calami*, or a typographical error is evident.

"*Article* 20.—In forming names derived from languages in which the Latin alphabet is used, the exact original spelling, including diacritic marks, is to be retained. Examples: *Selysius, Lamarckia, Köllikeria, Mülleria, Stålia, Krøyeria, Ibañezia, Möbiusi, Medići, Cžjžeki, spitzbergensis, islandicus, paraguayensis, patagonicus, barbadensis, färöensis*.

Author's Name.

"*Article* 21.—The author of a scientific name is that person who first publishes the name in connection with an indication, a definition or a description, unless it is clear from the contents of the publication that some other person is responsible for said name and its indication, definition, or description.

"*Article* 22.—If it is desired to cite the author's name, this should follow the scientific name without interposition of any mark of punctuation; if other citations are desirable (date, *sp. n., emend., sensu stricto*, etc.), these follow after the author's name, but are

separated from it by a comma or by parentheses. Examples: *Primates* Linné, 1758, or *Primates* Linné (1758).

"*Article* 23.—When a species is transferred to another than the original genus or the specific name is combined with any other generic name than that with which it was originally published, the name of the author of the specific name is retained in the notation but placed in parentheses. Examples: *Tænia lata* Linné, 1758, and *Dibothriocephalus latus* (Linné, 1758); *Fasciola hepatica* Linné, 1758, and *Distoma hepaticum* (Linné, 1758).

"If it is desired to cite the author of the new combination, his name follows the parentheses. Example: *Limnatis nilotica* (Savigny 1820) Moquin-Tandon, 1826.

"*Article* 24.—When a species is divided, the restricted species to which the original specific name of the primitive species is attributed may receive a notation indicating both the name of the original author and the name of the reviser. Example: *Tænia solium* Linné, *partim*, Goeze.

The Law of Priority.[1]

"*Article* 25.—The valid name of a genus or species can be only that name under which it was first designated on the condition:

"(*a*) That (*prior to January* 1, 1931) this name was published and accompanied by an indication, or a definition, or a description; and

"(*b*) That the author has applied the principles of binary nomenclature.

"(*c*) *But no generic name nor specific name, published after December* 31, 1930, *shall have any status of availability* (*hence also of validity*) *under the Rules, unless and until it is published either*

"1. *with a summary of characters* (*seu diagnosis; seu definition; seu condensed description*) *which differentiate or distinguish the genus or the species from other genera or species;*

"2. *or with a definite bibliographic reference to such summary of characters* (*seu diagnosis; seu definition; seu condensed description*). *And further*

"3. *in the case of a generic name, with the definite unambiguous designation of the type species* (*seu genotype; seu autogenotype; seu orthotype*).

Application of the Law of Priority.

"*Article* 26.—The tenth edition of Linné's *Systema naturæ*, 1758, is the work which inaugurated the consistent general application of the binary nomenclature in zoölogy. The date 1758, therefore, is

[1] Italicized type represents the amendment adopted by the International Zoölogical Congress, which met in Budapest, September 4 to 9, 1927.

accepted as the starting point of zoölogical nomenclature and of the law of priority.

"*Article* 27.—The law of priority obtains and consequently the oldest available name is retained:

"(*a*) When any part of an animal is named before the animal itself;

"(*b*) When the larva is named before the adult;

"(*c*) When the two sexes of an animal have been considered as distinct species or even as belonging to distinct genera;

"(*d*) When an animal represents a regular succession of dissimilar generations which have been considered as belonging to different species or even to different genera.

"*Article* 28.—A genus formed by the union of two or more genera or subgenera takes the oldest valid generic or subgeneric name of its components. If the names are of the same date, that selected by the first reviser shall stand.

"The same rule obtains when two or more species or subspecies are united to form a single species or subspecies.

"*Article* 29.—If a genus is divided into two or more restricted genera, its valid name must be retained for one of the restricted genera.

"If a type was originally established for said genus, the generic name is retained for the restricted genus containing said type.

"*Article* 30.—If the original type of a genus was not indicated, the author who first subdivides the genus may apply the name of the original genus to such restricted genus or subgenus as may be judged advisable, and such assignment is not subject to subsequent change.

"In no case, however, can the name of the original genus be transferred to a group containing none of the species originally included in the genus; nor can a species be selected as type which was not originally included in the genus or which the author of the generic name doubtfully referred to it.

"*Article* 31.—The division of a species into two or more restricted species is subject to the same rules as the division of a genus. But a specific name which undoubtedly rests upon an error of identification cannot be retained for the misdetermined species even if the species in question are afterward placed in different genera. Example: *Tænia pectinata* Goeze, 1782 = *Cittotænia pectinata* (Goeze), but the species erroneously determined by Zeder, 1800, as "*Tænia pectinata* Goeze" = *Andrya rhopalocephala* (Riehm); the latter species does not take the name *Andrya pectinata* (Zeder).

Rejection of Names.

"*Article* 32.—A generic or a specific name, once published, cannot be rejected, even by its author, because of inappropriateness.

Examples: Names like *Polyodon, Apus, albus,* etc., when once published, are not to be rejected because of a claim that they indicate characters contradictory to those possessed by the animals in question.

"*Article* 33.—A name is not to be rejected because of tautonymy, that is, because the specific or the specific and subspecific names are identical with the generic name. Examples: *Trutta trutta, Apus apus apus.*

"*Article* 34.—A generic name is to be rejected as a homonym when it has previously been used for some other genus of animals. Example: *Trichina* Owen, 1835, nematode, is rejected as homonym of *Trichina* Meigen, 1830, insect.

"*Article* 35.—A specific name is to be rejected as a homonym when it has previously been used from some other species of the same genus. Example: *Tænia ovilla* Rivolta, 1878 (*n. sp.*) is rejected as homonym of *T. ovilla* Gmelin, 1790.

"When in consequence of the union of two genera, two different animals having the same specific or subspecific name are brought into one genus, the more recent specific or subspecific name is to be rejected as a homonym.

"*Article* 36.—Rejected homonyms[1] can never be again used. Rejected synonyms can again be used in case of the restoration of erroneously suppressed groups. Example: *Tænia Giardi* Moniez, 1879, was suppressed as a synonym of *Tænia ovilla* Rivolta, 1878; later it was discovered that *Tænia ovilla* was preoccupied (*Tænia ovilla* Gmelin, 1790). *Tænia ovilla,* 1878, is suppressed as a homonym and can never again be used; it was still-born and cannot be brought to life, even when the species is placed in another genus (*Thysanosoma*). *Tænia Giardi,* 1879, which was suppressed as a synonym, becomes valid upon the suppression of the homonym *Tænia ovilla* Rivolta."

DISCUSSION.

While this code is not mandatory on workers in zoölogy and allied sciences, it has been urged in the interests of uniformity. Furthermore, it has now come to receive almost universal recognition. Unfortunately the terminology of animal parasites which appear in manuals of pathology and clinical diagnosis is usually antiquated, so that the student of medicine in taking up the subjects of parasitology and tropical medicine is frequently bewildered by having to recognize old forms under new names. Such real difficulties as these almost always bring about inquiries as to why the names of

[1] A homonym is defined by Stiles as "one and the same name for two or more different things. Synonyms are different names for one and the same thing."

zoölogical species, when once established, should require continual revision. In answering the difficulty it may be stated that if the first designation of a species following the year 1758 had been accurate, and if the published description of the species had been sufficiently complete to enable subsequent workers to recognize the species, then under ordinary circumstances this should be the legal name of the species. In many cases, however, the early investigators published inaccurate or inadequate diagnoses of species. They frequently failed to differentiate related species one from the other. At times their descriptions applied to two or more related species. Linnæus himself (1758) grouped the beef tapeworm of man (*T. saginata* Goeze, 1782) and the tænia of the dog (*T. hydatigena* Pallas, 1766), together with the pork tapeworm of man, under the single name *Tænia solium*. Likewise, in many instances the accumulation of data through the years has required the division of one genus such as *Distoma* Retzius, 1790, which originally included all of the distomate digenetic flukes, into many genera, so that such species as *Fasciolopsis buski* (Lank., 1857), *Clonorchis sinensis* (Cobbold, 1875), and *Paragonimus westermani* (Kerbert, 1878), which had originally been placed in the genus *Distoma*, were removed by later workers for good and sufficient reasons and placed in more restricted groups. Furthermore, where two or more investigators described the same species at about the same time under different names, it has been necessary to discover which of these names has priority and which is to be regarded as a synonym of the other. [Example: *Fasciolopsis buski* (Lank., 1857) has priority over *F. crassum* (Cobbold, 1860), the latter being a synonym.] Again, numberous instances have come to light in which an original description (*post* 1758) had long been buried in the literature and actually had priority over commonly recognized names subsequently given. Fortunately for the medical man such instances in medical zoölogy are not common.

In the case of genera it is not permitted to use the same generic name in more than one group of the Animal Kingdom. Hence the term *Trichina* Owen, 1835 was found by Railliet to be unavailable for the nematode parasite which had commonly been referred to as "*Trichina spiralis*," because it had been previously used for a group of Diptera (1830). In consequence of this fact Railliet (1895) renamed the nematode genus *Trichinella*.

In no small number of cases the larval stage of the worm was known and described before the adult had been discovered. According to the rules the first name given to any stage of the life cycle of an organism (Article 27*b*) has precedence over a later one, even though that first name was used to designate the larva. Thus *Echinococcus granulosus* (Goeze, 1786) has priority over *Echino-*

coccifer echinococcus (Zeder, 1803) Weinland, 1858 and *Tænia echinococcus* (Zeder, 1803), whether reference is made to the hydatid in man, sheep, ox and pig or to the adult tapeworm in the dog. *Strongyloides stercoralis* (Bavay, 1876), first designated for the free-living stage of the Cochin-China worm, also takes precedence over *Strongyloides intestinalis* (Bavay, 1877), the name first applied to the parasitic generation.

In a few instances involving helminths parasitic in man, forms originally believed to be different species of the same genus are now known to be one and the same species. Thus *Clonorchis sinensis* (Cobbold, 1875) and *C. endemicus* (Baelz, 1883) have been united under the name *Clonorchis sinensis*, and *Fasciolopsis buski* (Lank., 1857), *F. rathouisi* (Poirier, 1887), *F. fülleborni* Rodenwaldt, 1909, and *F. goddardi* Ward 1909 are all now referred to as *Fasciolopsis buski.*

Confusion in synonymy has also been due to considering organisms morphologically similar but occurring in different hosts or in the same hosts in different geographical areas as distinct species. A case in point is *Paragonimus westermani* (Kerbert, 1878) from the tiger and *P. ringeri* (Cobbold, 1880) from man. Since the species from man is now considered to be identical with that from the tiger the human parasite is designated by the earlier name. Another case in point is the hookworm of the tropics and subtropics, originally described by Gomez de Faria (1910) from the dog and the cat in Rio as *Ancylostoma braziliense* and by Looss (1911) from the civet cat in Ceylon as *A. ceylanicum*. Until recent years these were believed to be different species but have lately been considered as identical. There is still doubt as to whether the common ascarid of man and of the pig is one and the same species. Although the worms are morphologically the same the pig has not yet been proved to be a physiologically adapted host for strains of the organism originating from man. On the other hand experimental evidence is fairly convincing that the dwarf tapeworm of man, *Hymenolepis nana* (v. Siebold, 1852) is identical with *Hymenolepis fraterna* Stiles, 1906, of the rat. In such instances where the human material was first described no serious difficulty arises in nomenclature for the medical man, but where the description of the parasites from man does not take precedence over that from other hosts it is important for the medical man to know whether there are prior claims that must be recognized.

Perhaps the greatest difficulty in the whole system of nomenclature and certainly that working the greatest hardship for medical men, is the sudden change of a long established name for what seems to be a new one. For example, the broad tapeworm commonly referred to as "*Bothriocephalus latus*" or "*Dibothriocephalus latus*"

has within recent years been renamed "*Diphyllobothrium latum*," in view of the fact that the genus *Bothriocephalus* belongs to a family group, the adults of which live in the intestines of fishes, having features unlike the broad tapeworm and its allies, the adults of which live only in the intestines of mammals and of birds. The recent removal of the filaria, commonly referred to as "*Filaria bancrofti*" to *Wuchereria* (*i. e.*, *Wuchereria bancrofti*), the pinworm, "*Oxyuris vermicularis*" to *Enterobius* (*i. e.*, *Enterobius vermicularis*), and the guinea-worm "*Dracunculus medinensis*" to *Fuellebornius* (*i. e.*, *Fuellebornius medinensis*) have been based on different but justifiable grounds, but, to the student not interested in the technical details of nomenclature, such changes may appear to be ill-advised. It is recognized that long continuous usuage, particularly of terms commonly employed in medicine, might rightly constitute a sufficient reason for setting aside the strict application of the rules of nomenclature, but, on the other hand, if exceptions are made in one series of cases, it is altogether likely that other types of exceptions might be asked for on equally plausible grounds.

Only one name applied to a helminth parasite of man has given rise to real orthographic difficulties. That name is the one used for the hookworm originally described by Dubini (1843) as *Agchylostoma duodenale.* In view of the fact that the first two syllables of the generic name as given by Dubini were barbarian rather than classical in their origin the International Commission on Zoölogical Nomenclature adopted *Ancylostoma* as the correct form. Such variants as *Anchylostoma, Ankylostoma* and *Ankylostomum* are therefore not considered proper usage. As a matter of consistency the term designating an infection with hookworm of the genus *Ancylostoma* should be ancylostomiasis and not anchylostomiasis or ankylostomiasis. (Uncinariasis, which is commonly employed to designate infection with *Necator americanus*, should be reserved for infections with *Uncinaria*, a genus of hookworms occurring in the dog, cat, fox, pig and badger.) In this connection the term "*Bilharzia*" which is commonly used for the blood-fluke infections, *Schistosoma hæmatobium* and *S. mansoni*, is an absolute synonym of the term *Schistosoma*, and should never be used in a nomenclatural sense.

Enough has been said by way of comment to show that the Code of Zoölogical Nomenclature, although necessarily arbitrary, is entirely consistent, and that difficulties which have arisen have resulted from inherent errors in designations made by various authors or by their incorrect application of the rules. The correct names of the known entozoic helminth parasites of man, together with the correct pathological terms for infections with these parasites, are as follows:

NAMES OF HELMINTH PARASITES OF MAN AND PATHOLOGICAL DESIGNATION FOR INFECTIONS WITH THESE PARASITES.

Name of Parasite	Pathological Designation for Infection with this Parasite[1]
PLATYHELMINTHES	
TREMATODA	trematodiasis
**Schistosoma hæmatobium* (Bilharz, 1852)	schistosomiasis hæmatobia
Schistosoma bovis (Sonsino, 1876)	schistosomiasis bovis
**Schistosoma japonicum* Katsurada, 1904	schistosomiasis japonica
**Schistosoma mansoni* Sambon, 1907	schistosomiasis mansoni
Watsonius watsoni (Conyngham, 1904)	watsoniasis watsoni
Gastrodiscoides hominis (Lewis and McConnell, 1876)	gastrodiscoidiasis hominis
Fasciola hepatica Linnæus, 1758	fascioliasis hepatica
Fasciola gigantica Cobbold, 1855	fascioliasis gigantica
**Fasciolopsis buski* (Lankester, 1857)	fasciolopsiasis buski
Echinostoma ilocanum Garrison, 1908	echinostomiasis ilocana
Echinostoma malayanum Leiper, 1911	echinostomiasis malayana
Echinostoma jassyense (Léon and Ciurea, 1922)	echinostomiasis jassyensis
Echinostoma sufrartyfex (Lane, 1915)	echinostomiasis sufrartyfex
**Echinochasmus perfoliatus* v. Ratz, 1908	echinochasmiasis perfoliata
Dicrocœlium dendriticum Rud., 1819	dicrocœliiasis dendritica
Eurytrema pancreaticum (Janson, 1889)	eurytremiasis pancreatica
**Heterophyes heterophyes* (v. Siebold, 1852)	heterophyiasis heterophyes
Heterophyes katsuradai Ozaki and Asada, 1925	heterophyiasis katsuradai
**Metagonimus yokogawai* Katsurada, 1912	metagonimiasis yokogawai
Stamnosoma armatum Tanabe, 1922	stamnosomiasis armata
Stamnosoma formosanum Nishigori, 1924	stamnosomiasis formosana
Monorchotrema taihokui Nishigori, 1924	monorchotremiasis taihokui
Monorchotrema taichui Nishigori, 1924	monorchotremiasis taichui
**Opisthorchis felineus* (Rivolta, 1884)	opisthorchiasis felinea
Opisthorchis viverrini (Poirier, 1886)	opisthorchiasis viverrini
Opisthorchis noverca Braun, 1902	opisthorchiasis noverca
**Clonorchis sinensis* (Cobbold, 1875)	clonorchiasis sinensis
Pseudamphistomum truncatum (Rud., 1819)	pseudamphistomiasis truncata
**Paragonimus westermani* (Kerbert, 1878)	paragonimiasis westermani
†*Isoparorchis trisimilitubis* Southwell, 1914	isoparorchiasis trisimilitubis

[1] Formed by the addition of "iasis" to the root of the genus name and requiring agreement of the species name in case the latter is an adjective. Pathological terms are not capitalized.

* Common helminth infections of man.

† Accidental or pseudo-parasites.

Name of Parasite	Pathological Designation for Infection with this Parasite[1]
CESTODA	cestodiasis
**Diphyllobothrium latum* (Linn., 1758)	diphyllobothriiasis lata
Diphyllobothrium cordatum (Leuckart, 1863)	diphyllobothriiasis cordata
Diphyllobothrium houghtoni Faust, Campbell and Kellogg, 1929	diphyllobothriiasis houghtoni
Diphyllobothrium mansoni (Cobbold, 1882)	diphyllobothriiasis mansoni
Diphyllobothrium parvum (Stephens, 1908)	diphyllobothriiasis parva
Diplogonoporus grandis (Blanchard, 1894)	diplogonoporiasis grandis
Diplogonoporus brauni (Léon, 1907)	diplogonoporiasis brauni
Braunia jassyensis Léon, 1908	brauniiasis jassyensis
**Sparganum mansoni* (Cobbold, 1882)	sparganiasis mansoni, or sparganosis mansoni
Sparganum proliferum (Ijima, 1905)	sparganiasis prolifera, or sparganosis prolifera
Sparganum baxteri Sambon, 1907	sparganiasis baxteri, or sparganosis baxteri
Bertiella satyri (Blanchard, 1891)	bertielliasis satyri
Dipylidium caninum (Linn., 1758)	dipylidiiasis canina
Hymenolepis diminuta (Rud., 1819)	hymenolepiasis diminuta
**Hymenolepis nana* (v. Siebold, 1852)	hymenolepiasis nana
Drepanidotænia lanceolata (Bloch, 1782)	drepanidotæniiasis lanceolata
Davainea madagascariensis (Davaine, 1869)	davaineiasis madagascariensis
Davainea formosana Akashi, 1916	davaineiasis formosana
Raillietina asiatica (v. Linstow, 1901)	raillietiniasis asiatica
**Tænia solium* Linn., 1758	tæniiasis solium
**Tænia saginata* Goeze, 1782	tæniiasis saginata
Tænia confusa Ward, 1896	tæniiasis confusa
Tænia africana v. Linstow, 1900	tæniiasis africana
Multiceps multiceps (Leske, 1780)	multicipiasis multiceps
Multiceps glomeratus Rail. and Henry, 1915	multicipiasis glomerata
**Echinococcus granulosus* (Batch, 1786)	echinococciasis granulosa, or echinococcosis granulosa
NEMATHELMINTHES	
NEMATODA	nematodiasis
**Trichocephalus trichiurus* (Linn., 1771)	trichocephaliasis trichiura
Hepaticola hepatica (Bancroft, 1893)	hepaticoliasis hepatica
**Trichinella spiralis* (Owen, 1835)	trichinelliasis spiralis, or trichinosis spiralis
**Strongyloides stercoralis* (Bavay, 1876)	strongyloidiasis stercoralis, or strongyloidosis stercoralis
†Rhabditis pellio (Schneider, 1866)	rhabditiasis pellio

[1] Formed by the addition of "iasis" to the root of the genus name and requiring agreement of the species name in case the latter is an adjective. Pathological terms are not capitalized.

* Common helminth infections of man.

† Accidental or pseudo-parasites.

Name of Parasite	Pathological Designation for Infection with this Parasite[1]
†*Rhabditis niellyi* (Blanchard, 1885)	rhabditiasis niellyi
†*Rhabditis hominis* Kobayashi, 1914	rhabditiasis hominis
†*Turbatrix aceti* (Mueller, 1783)	turbatrichiasis aceti
†*Anguillulina putrefaciens* (Kuehn, 1879)	anguilluliniasis putrefaciens
†*Heterodera radicicola* (Greef, 1872)	heteroderiasis radicicola
Ternidens deminutus (Rail. and Henry 1905)	ternidentiasis deminuta
Œsophagostomum apiostomum (Willach, 1891)	œsophagostomiasis apiostoma
Œsophagostomum stephanostomum, var. *thomasi* Rail. and Henry, 1909	œsophagostomiasis stephanostoma, var. thomasi
Syngamus kingi Leiper, 1913	syngamiasis kingi
Trichostrongylus colubriformis (Giles, 1892)	trichostrongyliasis colubriformis, or trichostrongylosis colubriformis
Trichostrongylus probolurus (Rail., 1896)	trichostrongyliasis probolura, or trichostrongylosis probolura
Trichostrongylus vitrinus Looss, 1905	trichostrongyliasis vitrina, or trichostrongylosis vitrina
Trichostrongylus orientalis Jimbo, 1914	trichostrongyliasis orientalis, or trichostrongylosis orientalis
Hæmonchus contortus (Rud., 1803)	hæmonchiasis contorta
Mecistocirrus digitatus (v. Linstow, 1906)	mecistocirriasis digitata
**Ancylostoma duodenale* (Dubini, 1843)	ancylostomiasis duodenalis
**Ancylostoma braziliense* de Faria, 1910	ancylostomiasis braziliensis
Ancylostoma malayanum (Alessandrini, 1905)	ancylostomiasis malayana
**Necator americanus* (Stiles, 1902)	necatoriasis americana
Metastrongylus apri (Gmelin, 1790)	metastrongyliasis apri, or metastrongylosis apri
Dioctophyme renale (Goeze, 1782)	dioctophymiasis renalis
**Enterobius vermicularis* (Linn., 1758)	enterobiiasis vermicularis
Syphacia obvelata (Rud., 1802)	syphaciiasis obvelata
**Ascaris lumbricoides* Linn., 1758	ascariasis lumbricoides
Toxocara canis (Werner, 1782)	toxocariasis canis
Belascaris cati (Schrank, 1788)	belascariasis cati
Lagochilascaris minor Leiper, 1909	lagochilascariasis minor
Gongylonema pulchrum Molin, 1857	gongylonemiasis pulchra
Gnathostoma spinigerum Owen, 1836	gnathostomiasis spinigera
Gnathostoma hispidum Fetsch., 1872	gnathostomiasis hispida
Physaloptera caucasica v. Linst., 1902	physalopteriasis caucasica
Thelazia callipæda Rail. and Henry, 1910	thelaziiasis callipæda

[1] Formed by the addition of "iasis" to the root of the genus name and requiring agreement of the species name in case the latter is an adjective. Pathological terms are not capitalized.

* Common helminth infections of man.

† Accidental or pseudo-parasites.

Name of Parasite	Pathological Designation for Infection with this Parasite[1]
**Wuchereria bancrofti* (Cobbold, 1877)	wuchereriiasis bancrofti (or "filariasis" bancrofti)
Dirofilaria magalhæsi (Blanchard, 1895)	dirofilariiasis magalhæsi
**Onchocerca volvulus* (Leuckart, 1893)	onchocerciasis volvula
**Onchocerca cæcutiens* Brumpt, 1919	onchocerciasis cæcutiens
**Loa loa* (Cobbold, 1864)	loaiasis loa
**Acanthocheilonema perstans* Manson, 1891	acanthocheilonemiasis perstans
Mansonella ozzardi (Manson, 1897)	mansonelliasis ozzardi
**Fuellebornius medinensis* (Linn., 1758)	fuelleborniiasis medinensis, or dracunculosis medinensis, or dracontiasis medinensis
ACANTHOCEPHALA	acanthocephaliasis
Macracanthorhynchus hirudinaceus (Pallas, 1781)	macracanthorhynchiasis hirudinacea
Moniliformis moniliformis (Bremser, 1819)	moniliformiasis moniliformis

[1] Formed by the addition of "iasis" to the root of the genus name and requiring agreement of the species name in case the latter is an adjective. Pathological terms are not capitalized.

* Common helminth infections of man.

† Accidental or pseudo-parasites.

NOTE.—The common helminth infections of man are frequently referred to in pathological diagnoses by the single term derived from the generic name of the parasite, as, for example, clonorchiasis for *Clonorchis sinensis* infection, and ascariasis for *Ascaris lumbricoides* infection. This is permissible only in case there is only one species of this genus recorded from man

CHAPTER VI.

THE LITERATURE OF HELMINTHOLOGY.

INTRODUCTION.

Sufficient evidence has already been produced to show that many of the original sources of helminthology extend back into ancient history. Several others precede the Linnæan system of binomial nomenclature. However, the great bulk of helminthological literature has developed within the past one hundred and twenty-five years, and of this period the first seventy-five years was given up primarily to the morphology and taxonomy of species of helminths not directly relevant to human helminthology. The more important knowledge on the morphology, biology and life cycles of helminths parasitic in man, together with their epidemiological settings and clinical bearings has developed within the past half century. Even within this period manuals or texts on helminthology have become out-of-date almost as soon as they have been published, so rapid has been the development of the subject. Of the texts preceding the beginning of the twentieth century Leuckart's "Parasiten" alone is of value except from an historical viewpoint. Likewise almost all of the present-day periodicals, specialized in presenting parasitological information in one or more of its several aspects, have sprung into existence within this same period, thus indicating the expansion of the field of parasitic infections within very recent times.

It is obviously impossible to list all of the manuals or texts dealing wholly or in part with helminthic diseases and the organisms which are their cause. It is equally impossible to mention all of the journals in which papers dealing with helminthological material are published. Much of the biological data is found in purely biological journals; much of the clinical work appears in purely medical publications. There is, however, an important group of journals and periodicals which is devoted primarily to parasitic diseases together with their causative organisms. The more important texts and journals, dealing primarily with such material, and including no small amount of information about helminthology, are listed here for suggested collateral reading. Monographs and important papers on particular groups and species of helminths are to be found under their respective headings.

GENERAL LITERATURE ON HELMINTHOLOGY.

A. Manuals and Textbooks.

Braun, M., and Seifert, O.: Die Tierischen Parasiten des Menschen, 6th ed., Leipzig, 1925. (General text on human parasitology.)

Brumpt, E.: Precis de parasitologie, 3d ed., Paris, 1922; 4th ed., 1927. (General text on human parasitology.)

Castellani, A., and Chalmers, A. J.: A Manual of Tropical Medicine, 3d ed., London, 1919. (Extensive treatment of both the biological and clinical aspects of parasitic diseases.)

Chandler, A. C.: Animal Parasites and Human Disease, 3d ed., New York, 1926. (Written particularly for beginners in medical zoölogy.)

Fantham, H. B., Stephens, J. W. W., and Theobald, F. V.: The Animal Parasites of Man, London and New York, 1916. (General text on human parasitology.)

Gamble, F. W.: Platyhelminthes and Mesozoa, Vol. II in *The Cambridge Natural History*, London, 1922. (Biology of the Flatworms.)

Hegner, R. W., Cort, W. W., and Root, F. M.: Outlines of Medical Zoölogy, New York, 1923; Part II. Worms Parasitic in Man. (Introduction to medical helminthology.)

Hegner, R., Root, F. M., and Augustine, D. L. Animal Parasitology. Section 2, Helminthology. New York, 1929.

Lane, C., et al.: Helminthiasis, Section XI of Byam and Archibald's *The Practice of Medicine in the Tropics*, Vol. III, London, 1923. (Chapters by specialists on the more important helminthic infections.)

Leuckart, R.: Die Parasiten des Menschen und die von ihnen herrührenden Krankheiten, Leipzig, 1879–1886. (Very valuable source book for investigators.)

Manson-Bahr, P. H.: Manson's Tropical Diseases, 8th ed., London, 1925. (Important discussion of the clinical aspects of helminthic infections.)

Mathis, C., and Leger, M.: Recherches de parasitologie et de pathologie humaines et animales au Tonkin, Paris, 1911. (Valuable research contribution to the parasitology of French Indo-China.)

Shipley, A. E.: Nemathelminthes, Vol. II in *The Cambridge Natural History*, London, 1922. (Biology of the nematodes and acanthocephalans.)

Simon, C. E.: A Manual of Clinical Diagnosis by Means of Laboratory Methods, 10th ed., Philadelphia, 1922. (Helminths and the clinical laboratory.)

Stiles, C. W.: The International Code of Zoölogical Nomenclature as Applied to Medicine, Hyg. Lab. Bull., No. 24, Washington, 1905.

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SECTION II.

THE PLATYHELMINTHES OR FLATWORMS.

CHAPTER VII.

THE FLATWORMS AS A GROUP.

GENERAL CONSIDERATIONS.

LINNÆUS (1758) and biologists of his day referred to all metazoal organisms which were more or less worm-like at one time or another of their life cycle as **Vermes** or "worms." More strictly speaking, the term "Vermes" has, within later years, come to be utilized as a group name for all flatworms, roundworms and annelids or segmented worms, each of which belongs to a distinct phylum of the **Animal Kingdom**. Of these three phyla, the most simple in organization and that nearest the archetype of the bilaterally symmetrical Metazoa is the group of the flatworms or **Platyhelminthes**.

The **Platyhelminthes** comprise all of those species of worms which are bilaterally symmetrical and which are usually compressed dorso-ventrally. There is no body cavity in the definitive stage of the organism, the space being filled with spongy undifferentiated mesenchymatous cells. The nervous system consists of paired ganglia with transverse commissures at the proximal end of the worm, and longitudinal nerve tracts arising from the brain cells and proceeding posteriad to the distal end of the organism. In addition, there are numerous sensory endings and, at times, eye-spots in the proximal region. For all practical purposes the proximal end of a flatworm may be regarded as the anterior or cephalic end. Some members of this phylum are characterized by having a single gastric cavity, which, if present, ordinarily terminates blindly without an anus. Furthermore, they possess a bilaterally symmetrical excretory system, consisting of a bladder, collecting tubules, capillaries and terminal "flame-cells" or solenocytes. The "flame-cells" are so designated because they, as the terminal cells of the capillaries, are each provided with a group of vibratile cilia, which lie within the enlarged termini of the capillaries and beat in unison so as to give the appearance of a flickering candle flame. In the absence of a circulatory system (except in the group of the nemer-

teans) the excretory system cares for the elimination of all liquid and gaseous wastes from the intimate tissues of the body.

The sexual organs of the **Platyhelminthes** call for special consideration. They are complicated and consist of both primary and secondary organs of both sexes. Usually both sexes are combined in a single organism, which is consequently hermaphroditic. Each organism is thus self-sufficient in the production of fertilized eggs. In the majority of the tapeworms the body is segmented and each segment carries a complete set of male and female reproductive organs. In a few species (*Dipylidium, Diplogonoporus*) there is a double set of reproductive organs. In addition to bisexual propagation, other methods of reproduction may be intercalated, as, for example, budding in the Turbellaria and Cestodes, and parthenogenesis in the Trematodes.

Development may be direct, as in the case of certain Turbellaria and ectoparasitic trematodes; or it may require a larval stage with metamorphosis, as in the cestodes; or it may consist in an alternation (*metagenesis*) of marital and parthogenetic generations, as in the endoparasitic trematodes.

The phylum **Platyhelminthes** is usually divided into four classes, the Turbellaria, the Trematoda, the Cestoda and the Nemertea. The last-named group consists almost exclusively of free-living forms, possessing, in addition to a circulatory system, a conspicuous proboscis and an anus. The relationship of this class to the other members of the phylum is still questionable.

CLASSIFICATION OF THE FLATWORMS.

Phylum **Platyhelminthes** Claus, 1880.

Many-celled animals, usually leaf- or tape-like, rarely cylindrical; bilaterally symmetrical; with three layers; gastro-vascular cavity, when present, single, ordinarily without an anal opening; without a body cavity; excretory system provided with flame-cells.

Class I.—Turbellaria Ehrenberg, 1831.

Mostly free-living organisms, only a few species being commensals or parasites; body covered with cilia; with or without a sucker; circulatory system lacking; development usually direct, without metamorphosis; reproduction hermaphroditic.

Class II.—Trematoda Rudolphi, 1808.

Parasitic organisms; adults covered with a non-ciliated integument; ciliated epithelium confined to larvæ hatched from eggs; suckers almost always present; circulatory system lacking; alimentary canal present except in the sporocyst generation of the Digenea.

Class III.—CESTODA Rudolphi, 1808.

Parasitic organisms; adults hermaphroditic, covered with a non-ciliated integument; ciliated epithelium when present confined to larvæ hatched from eggs; scolex provided with suckers and frequently with hooks; circulatory system lacking; no alimentary canal; body in almost all species divided into segments.

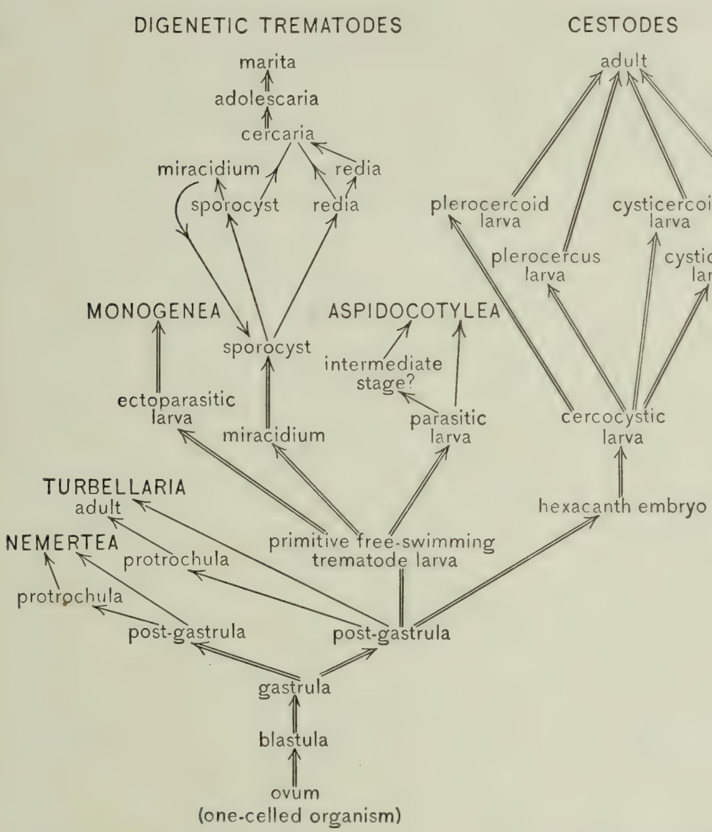

FIG. 2.—Synoptic diagram of the origin and relationship of the platyhelminths.

Class IV.—NEMERTEA Ehrenberg, 1831.

Almost exclusively free-living organisms; body covered with cilia; with a proboscis and an anus; circulatory system present; animals mostly unisexual; reproduction direct or with larval stage.

Since only the trematodes and cestodes are parasitic in man, attention will be directed in the following pages to these two groups.

The relationship and common origin of these four Classes of the Phylum **Platyhelminthes** are schematically represented in the diagram on page 67 (Fig. 2).

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CHAPTER VIII.

THE TREMATODES OR FLUKES.

STRUCTURE AND LIFE HISTORY.

THE trematodes or flukes are **Platyhelminthes** which are true parasites during a very large portion of their entire life. They derive their name from the fact that they are usually provided with conspicuous suckers (*e. g.*, are "pierced with holes"). There is almost a complete series of forms, representing on the one hand those species which are wholly ectoparasitic on aquatic hosts and, on the other, those species which have come to reside in the portal blood stream of vertebrates and are most intimately dependent on the particular host in which they live for their existence. Intermediate in the intimacy of their parasitic relationship are various species attached to the gills, buccal cavity, urinary bladder or intestine of their host. Those species which have attained only a superficial or ectoparasitic state of parasitism have a relatively simple life cycle, without alternation of generations; they are known as the **Monogenea** or monogenetic forms. On the other hand, those species which have developed a type of internal parasitism have become involved in a complicated life cycle, with alternation of generations; they are known as the **Digenea** or digenetic trematodes. All of the species parasitic in man belong to the digenetic trematodes.

The adult digenetic trematode (the *marita*) is usually visible to the naked eye (Fig. 3). It is covered with a protective integument provided with scales or spines and at times with a special armature of hooks around the oral opening. It is leaf-shaped, ovoid or at times nearly cylindrical. With few exceptions there is at least one well-developed sucker around the oral opening, and in most species there is at least one secondary sucker or acetabulum on the ventral surface of the fluke. In some instances this secondary acetabulum is much more conspicuous than the oral sucker. In the majority of species the oral sucker is situated near the anterior end of the body; however, in one group, the Gasterostomata, the oral opening with its sucker is mid-ventral in position. Within the oral sucker there is a pharynx or muscular sphincter, which, in turn, usually leads into an esophagus, which bifurcates anterior to the middle of the body to form a pair of ceca. These latter, after describing a wide arc laterad, proceed posteriorward to the subdistal region of the worm, where they end blindly.[1] The ceca may be simple (*Clonorchis*) or

[1] A few genera, as for example, *Balfouria*, possess an anal opening.

branched (*Fasciola*). They may even unite behind the middle of the body to form a single median stem (*Schistosoma*).

The nervous system in the digenetic trematode (Fig. 4) consists of paired ganglion cells with a saddle-like series of commissures dorsal to the pharynx and three main nerve trunks on either side, the dorsal, ateral and ventral trunks, extending anteriorward on the one hand

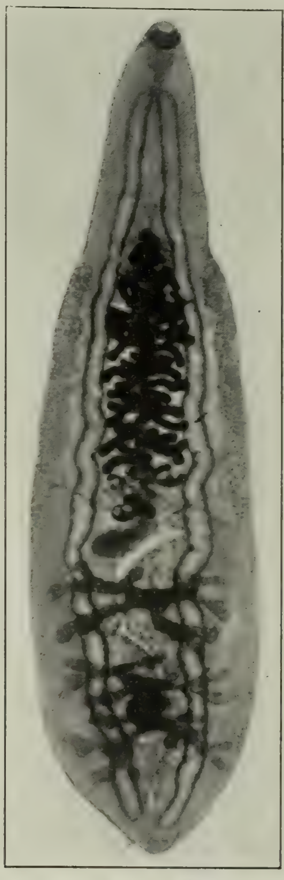

Fig. 3.—Mature *Clonorchis sinensis*, showing digestive, excretory and reproductive organs. (Original photograph.)

and posteriorward on the other. Around the anterior end of the body there are numerous sensory nerve endings and in some groups, particularly in the larval stages eye-spots are present (Fig. 5). Melanoid pigment may be found in the tissues superficial to the nervous system during the larval stages.

The excretory system (Fig. 6) consists of a median posteriorly disposed bladder, which opens through an excretory pore guarded by

a sphincter. On its anterior aspect, usually anterolaterally, the bladder receives a pair of collecting tubes, which, upon being traced forward, will be found to branch in a precise manner. This branch-

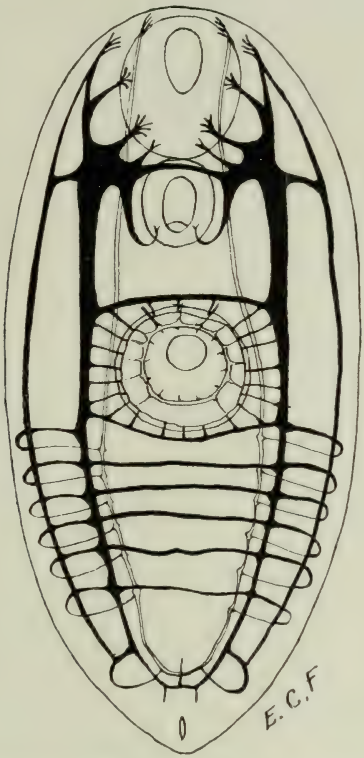

FIG. 4.—Nervous system of a digenetic trematode. (Adapted from Bettendorf.)

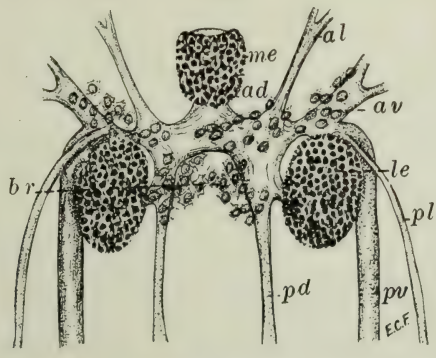

FIG. 5.—Cercarial stage of a trematode, showing ganglion cells, important nerve trunks and eyespots. (After Faust.)

ing may occur once or even several times, until the ultimate capillaries are reached, each one ending in a flame-cell or solenocyte, which is analogous and possibly homologous to the protonephridium of the vertebrate body. The pattern of the excretory system is an exact one; it is always the same for the same species of fluke; it is

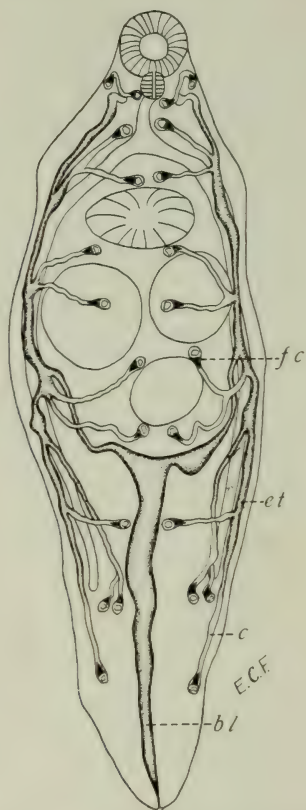

FIG. 6.—Excretory system in the adult *Dicrocœlium*. (Original.)

always reducible to a "least common denominator;" it differs in different families but is usually the same in closely related species. It is, therefore, an important structure in determining the relationship of species and of larvæ with adults. Thus the miracidium of most flukes (Fig. 9) has a single flame-cell on each side of its body; that of the blood flukes (Fig. 24) has two such flame-cells; and that of the Aspidocotylea has three. The fundamental flame-cell pattern of a given trematode species can most readily be studied in the cercarial stage, where the system is not ordinarily masked by opaque tissues or cell inclusions. In the cercaria of the human blood

flukes there are one anterior and one posterior pair of flame-cells on each side of the body. As the cercaria develops to adulthood the flame-cells multiply many times by a dichotomous division, so that the total number of such cells in the adult is an exact multiple of those in the cercaria. Thus the fundamental flame-cells pattern for the human blood flukes may be expressed as: $2 [(1 + 1) + (1 + 1)]$ or $2 [\alpha + \beta]$, where the figure "2" represents the bilateral condition, "α" the anterior and "β" the posterior group of cells.

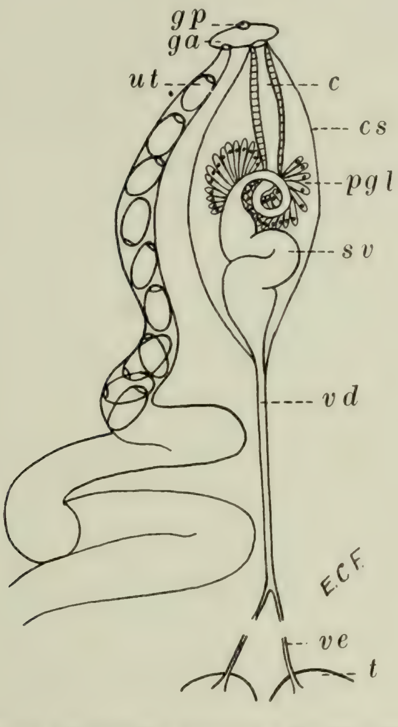

FIG. 7.—Male and female reproductive organs of a digenetic trematode in the region of the genital pore. (Original.)

The most conspicuous and most complicated organs of the adult trematode (the marita) are the generative or reproductive organs. All species of human trematodes except the blood flukes are hermaphroditic. Originally there was reciprocal copulation and many of the species still have provision for this process, but the great majority of the forms which have been studied depend on self-fertilization. The process can be better understood after the generative organs have been described.

The male reproductive organs consist of the following elements. The testes, typically two, are usually situated near the ovary.

They may lie in the same transverse plane or be situated obliquely to one another or in tandem arrangement. They may be rounded, lobed or dendritic in contour. From each testis (Fig. 7, *t*) there arises a vas efferens (*ve*) which is sooner or later joined by its mate to form the vas deferens (*vd*), which proceeds toward the genital atrium, enlarging before it reaches the genital atrium into a seminal vesicle (*sv*). This may be a simple enlargement of the duct or it may be retort-shaped or even tightly twisted upon itself. Anterior to the seminal vesicle there is usually a cluster of prostate glands (*pgl*), and frequently there is a muscular cirrus organ (*c*) just within the genital atrium. The seminal vesicle, prostate glands and cirrus organ, if present, are usually enclosed in an enveloping cirrus sac (*cs*). In the case of multiple testes (*e. g.*, *Schistosoma*) there is a vas

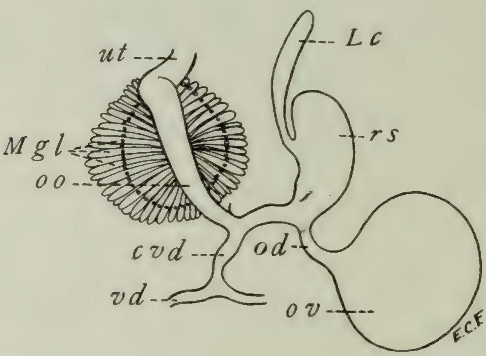

FIG. 8.—Female reproductive organs of a digenetic trematode. (Original.)

efferens for each testis. The spermatozoa which are produced by the testes pass up the ducts to the seminal vesicle where they are temporarily stored. They then pass out into the genital atrium (*ga*) thence up the uterus, proceeding through the oötype to the seminal receptacle, which constitutes the sperm reservoir of the female system.

The female organs (Fig. 8) consist of a single ovary (*ov*) in which the eggs develop, with its duct, the oviduct, through which the eggs when mature pass into the oötype (*oo*) or chamber where the naked ovum is transformed into the fertilized encapsulated egg. The ovary is usually rounded but may be lobed or dendritic. On its way to the oötype the oviduct receives a single vitelline duct (*vd*), which arises from the junction of a right and a left vitelline duct, each conveying the products to the common duct from the so-called vitellaria, which are usually situated in the extra-cecal fields and consist of clusters of glandular cells with yellowish refractive contents. Previous to receiving the common vitelline duct the

oviduct has been joined by the seminal receptacle (*sr*) with its dorsal outpocketing, Laurer's canal (*Lc*). This canal typically opens to the dorsal surface and is believed to represent a vestigial vagina through which originally insemination from another worm of the same species took place. In many species, however, Laurer's canal ends blindly without extending to the dorsal surface. In such cases spermatozoa reach the seminal receptacle only after migration up the uterus against the outward current of mature and maturing eggs. The oötype is surrounded by a cluster of acinus glands, known as Mehlis glands (*Mgl*) which are commonly referred to as "shell glands." Originating from the side of the oötype opposite the oviduct is the uterus (*ut*), which, after a more or less tortuous coiling, proceeds to the common genital atrium (Fig. 7, *ga*), which opens to the outside through the genital pore (*gp*). The terminal portion of the uterus is frequently referred to as the metraterm.

The process of egg-making, which occurs in the oötype, normally proceeds in the living mature worm with great regularity and precision. The mature ovum emerges from the ovary, passes into the oötype, and is fertilized by one of several spermatozoa that have either come in from the uterus or from the seminal receptacle. Meanwhile the yolk cells are added and the egg-shell is secreted. The assembled egg is then forced out of the oötype into the uterus, and another ovum comes into the oötype. The process is accomplished with the exact coördination of a complicated mechanism, each part of which operates with rhythm and speed synchronized to the whole. The eggs in the proximal end of the uterus are necessarily the youngest, while those in the distal portion are the most mature. The eggs are "laid" by being forced out of the genital atrium into the medium in which the worm resides. Sooner or later, in order to continue its life cycle, the egg must reach the outside world.

THE LIFE CYCLE OF DIGENETIC TREMATODES.

The digenetic trematodes not only have an alternation of generations (metagenesis) but also an alternation of hosts. The host of the generation producing fertilized eggs (*e. g.*, the marital generation) is usually a vertebrate; the intermediate host is always a mollusc. In addition, there is a required second intermediate host for many species of flukes. This host is frequently an arthropod or a lower vertebrate. The stage of the life cycle within the mollusc has at times been referred to as asexual, but careful investigation has shown that it is parthenogenetic. The life cycle of this group therefore involves an alternation of marital and parthenogenetic generations. Evidence favors the view that the parthenogenetic generations are the older, that the mollusc was the original host, and that

infection of the vertebrate host is a later adaptation. On the one hand, the uniformity of method utilized by the fluke in infecting the snail and of development within the snail, together with the relative equilibrium of molluscan host and trematode parasite, and, on the other, the variety of ways by which the fluke enters its definitive host, the variety of tissues which it parasitizes and the relative dysfunction which it causes in the tissues of the host, all support this view.

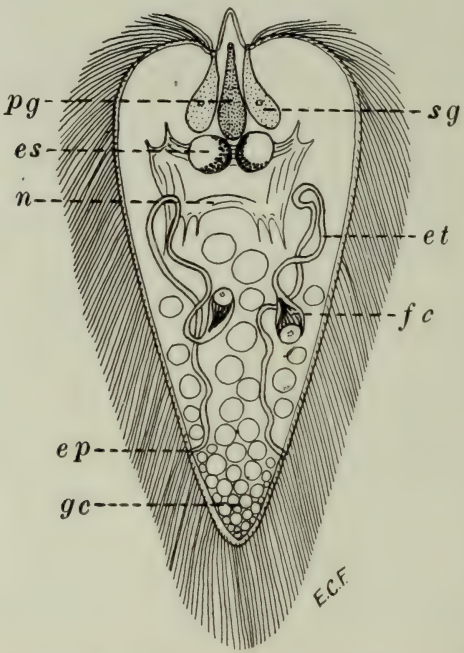

FIG. 9.—Miracidium of *Fasciolopsis buski*, showing ciliated epithelium, secretory glands, primitive gut, excretory system, nerve trunks, and proliferating germ cells. (Original.)

In order for the fertilized egg produced by the marita in the body of the definitive host to proceed with its development it must reach the outside world. Most flukes live in the intestinal tract of the definitive host or its adnexa. The eggs of those species parasitic in the bile passages reach the intestine through the common duct; the eggs of the lung flukes may be coughed up and either discharged in sputum or swallowed and voided in the feces. The eggs of *Schistosoma japonicum* and *S. mansoni* are expelled from the mesenteric capillaries into the intestinal lumen. Thus all of these eggs normally escape with the feces. On the other hand the eggs of *Schistosoma hæmatobium* ordinarily escape from the portal blood capillaries into the urinary bladder and are discharged in the urine.

Some of the eggs when laid, or at least when discharged in the host's excreta, already contain fully-formed mature larvæ, as, for example, those of the blood flukes, *Clonorchis, Dicrocœlium* and *Metagonimus*. On the other hand the eggs of *Fasciolopsis* and *Paragonimus* require a period of incubation after leaving the body of the definitive host before they are mature. The mature egg, when placed in an isotonic or slightly hypotonic medium, such as canal or pond water where feces may be deposited, usually responds by the energetic movement of the larva within, which soon causes the shell to open, either by the "popping off" of the operculum, if such be present, or by a splitting of the shell in non-operculate species. The larva now escapes into the free-water medium and for a brief period is a free-living organism.

The larva which escapes from the egg shell is the *miracidium* (literally, "little boy"). It is a very simple organism (Fig. 9), with a ciliated epithelial layer, a primitive sacculate gut (*pg*) opening at its anterior end, secretory glands (*sg*) which are usually paired, nerve ganglia (*n*), a pair of excretory tubules (*et*) with flame-cells (*fc*), and a group of germinal cells (*gc*) arising from the inner (usually posterior) wall and coming to lie free in the cavity of the larva. These cells arise from germinal epithelium, are produced after a reduction in chromosomes has taken place and are, therefore, parthenogenetic ova. They are the germ cells of the next generation.

The miracidium swims rapidly about in the water by means of its ciliated epithelium. In the event that it comes within the immediate vicinity of an appropriate species of mollusc to which it has become adapted, it swims headlong for this mollusc, probably impelled by a chemotactic stimulus, and attempts to penetrate the mollusc. If the larva impinges upon soft tissue it is able to attach itself by means of its glandular secretions and is able to digest its way into the tissues of the mollusc. This entrance may be through the gills (*Fasciola*) or by way of the head or foot (*Schistosoma*). In the case of *Clonorchis, Dicrocœlium* and probably *Metagonimus*, hatching of the miracidium does not occur in the water, although the larvæ of these species are provided with cilia for swimming. Evidence favors the view that hatching occurs only in the intestine of the favorable molluscan host, from whence the free miracidium penetrates into the peri-intestinal lymph spaces of the mollusc.

Once arrived within the tissues of the appropriate mollusc the miracidium soon reaches a natural lymph channel and gradually migrates from the oral toward the apical end of the mollusc. Meanwhile it has lost its cilia and has become metamorphosed into a simple sacculate object known as a *sporocyst*.[1] The sporocyst (Fig. 10) lies bathed in liquid nourishment. It performs all of its

[1] In some groups, as for example, the family **Echinostomatidæ**, the first generation parthenitæ may possibly be a redia.

metabolic processes by osmosis through its body wall. It has no need, therefore, for the usual organs of digestion, secretion, excretion or stimulation. It is devoted entirely to the production and development of its progeny (*gc*). In some species the germ cells which were first observed in the miracidium and have continued to grow as the sporocyst matures, develop into a second generation of sporocysts, more or less like the mother sporocyst. Such is the case with the second intra-molluscan generation of the blood flukes. However, in the majority of human trematodes the second generation becomes modified into a *redia* (Fig. 11), which is provided with

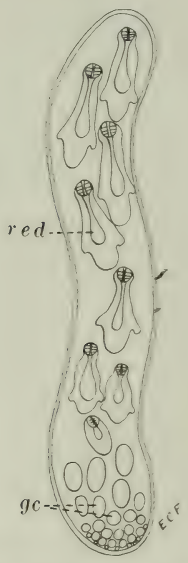

Fig. 10.—First generation parthenita (sporocyst), with second generation parthenitæ (rediæ) developing in the brood cavity. (Original.)

a pharynx (*ph*) and an undivided gut (*ce*), as well as a distinct excretory system (*et*), in addition to the posteriorly disposed germinal epithelium (*gc*). Some rediæ also have a birthpore (*bp*) and a pair of evaginate appendages (*evp*).

About the time the first generation sporocysts have reached the inter-hepatic lymph spaces of the mollusc, where the maximum amount of nourishment is to be secured, they are gravid with their progeny, which frequently number more than a hundred. The progeny soon rupture the wall of the sporocyst and lie free in the lymph fluid. Here they develop rapidly and their own progeny (those of the third generation) begin to take form. These may be a new generation of rediæ although in most species of flukes the organism of the third generation are essentially different from those

of the first two generations in that they almost never develop to adulthood within their molluscan host. Each one is commonly provided with a tail and is known as a *cercaria,* or tailed larvæ (Fig. 12). The various species of cercariæ also possess various types of secretory glands for use in penetration and encystment, as well as more highly differentiated digestive, excretory and integumentary systems. As few as ten or twelve or as many as several hundred cercariæ may be produced within a single second generation par-

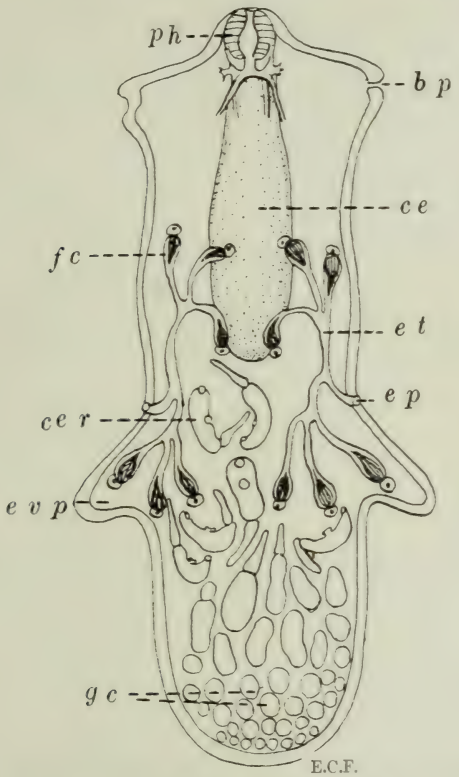

FIG. 11.—Fully developed second generation parthenita (redia), with pharynx, rhabdocele gut, excretory system and developing larvæ (cercariæ) of the third generation. (Original.)

thenita, depending in part on the species and in part on the supply of nourishment available. These cercariæ when mature escape from their mother sporocysts or rediæ either by rupturing the wall or emerging through the birth pore, if the latter be present. By their energetic movements they work their way through the enveloping layers of host tissues and finally lie free in the cavity between the mollusc and its shell. From this region they escape from time to

time into the water in which the mollusc lives and for a brief period are essentially free-living organisms.

The free-swimming cercaria swims about in the water by means of its tail. In the case of cercariæ with a bifid tail, the caudal organ precedes the body during the act of swimming; in all other cercariæ the body precedes the tail. The cercaria may attach itself by its

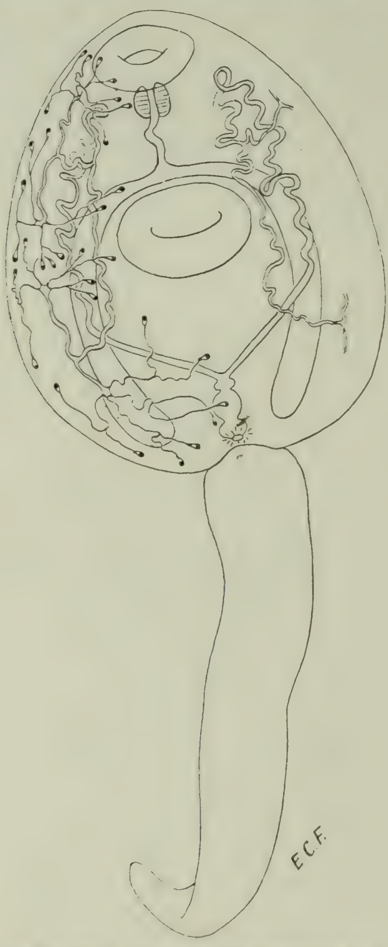

FIG. 12.—Cercaria of *Fasciola*, showing the digestive and excretory systems. (Original.)

suckers to the lower side of the surface film of water or it may sink to rest at the bottom of the water. Sooner or later, usually in twenty-four hours or less, the cercaria must effect measures for active or passive entrance into its definitive host. The blood flukes actively penetrate the tissues of their final host; all other flukes of which the life histories are known enter their final host passively, utilizing a

second intermediate host or vegetable tissue or at times even the same molluscan host, in or on which to encyst and await transfer.

Practically all cercariæ, are provided with unicellular secretory glands (the cephalic glands) with ducts opening in the vicinity of the oral sucker. These glands secrete a histolytic substance which digests host tissue. In the case of the blood flukes this secretion enables the larva to enter its final host; in the case of *Clonorchis*, *Metagonimus* and *Paragonimus*, it enables the cercaria to penetrate nto the tissues of a second intermediate host. In many other cases,

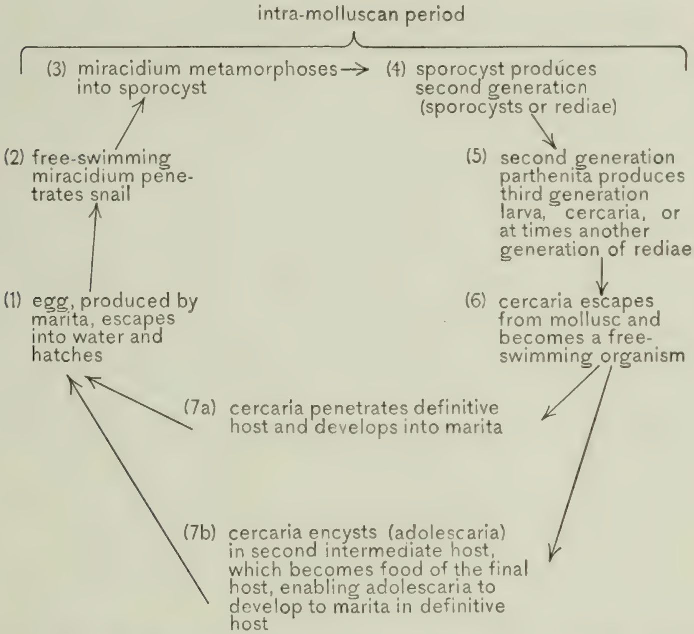

FIG. 13.—Synoptic diagram of the life cycle of a digenetic trematode. (Original.)

however, as in *Fasciolopsis*, these glands, although present, apparently do not function successfully. The majority of cercariæ are also provided with cystogenous glands in the mesenchyma which are packed with milky granules. After the cercaria has been free-swimming for a longer or shorter time in the *milieu* these granules swell up with water and are secreted as a viscous fluid through minute pores in the integument. Meanwhile the tail is discarded. The cystogenous substance "sets" in the form of an encapsulating cyst-membrane around the decaudated larva. The blood flukes lack these cystogenous glands. Encystment of those species which actively penetrate a second intermediate host occurs only after partial penetration of that host has taken place. In other cases it

occurs very soon after the cercaria has emerged from its molluscan host (monostomes, amphistomes, many distomes). In certain cases where the molluscan host is the food of the definitive host the cercaria encysts within the mollusc, and a few cases are known in which the cercaria even encysts within its mother parthenita. Thus these two types of secretory glands (cephalic and cystogenous) serve either singly or in coöperation in terminating the free-living existence of the cercaria.

After the cercaria has dropped its tail, and has either penetrated into its definitive host or has become encysted, it ceases to be called a cercaria and becomes known as an *adolescaria,* which includes the period between the cercaria and the marita. It is also referred to at times as the *metacercaria.* This stage in the life cycle of the blood flukes includes the period from the entrance through the skin of the final host to the maturity of the flukes in the portal blood stream. It is both a period of migration and of development. In those species which utilize a second intermediate host there is a passive incubation within this host, followed by a period of migration and development. Those species in which encystment takes place upon plant tissue (*Fasciola, Fasciolopsis,* etc.), differ from the latter in that the passive period of encystment is not one of growth for the adolescaria.

Unencysted adolescariæ cannot pass through the gastric secretions of vertebrate hosts and live. On the other hand encysted forms are uninjured by their passage through the stomach. On arriving in the medium of the intestinal secretions of the appropriate host, the cyst capsule is digested off, the adolescaria emerges and migrates to the place of its adult residence, where it develops into the marita.

The life cycle of the digenetic trematodes is epitomized in the synoptic diagram on page 81 (Fig. 13). It is more specifically illustrated for three types of human trematode infections in the following Figs.: *Schistosoma japonicum,* Fig. 18; *Fasciolopsis buski,* Fig. 78; *Clonorchis sinensis,* Fig. 106.

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CHAPTER IX.

THE TREMATODES OR FLUKES. CLASSIFICATION.

THE BASIS OF CLASSIFICATION.

THE trematode group is a very large one, comprising several thousands of species whose relationship to one another is as yet imperfectly understood. For that reasons any classification of the group is admittedly unsatisfactory. Much of the difficulty is due to the fact that in the past descriptions of all but a few species have been based exclusively on the morphological characteristics of the marita generation, the so-called "adult" trematode, without considering the life cycle of the organism in its entirety. Furthermore, the recognized classification adopted by systematists and commonly found in text-books is confined to the external features and the reproductive organs, frequently of preserved specimens only. Within recent years an attempt has been made to find other constant structures which might be relied upon to determine the relationships of the various species of the group one to another. Much has been learned from a study of the life cycle of some of the flukes. For example, although the specific or generic modifications of the reproductive organs of the marita cannot be recognized in the parthenita or in the cercaria, the excretory system, with its tubules, capillaries and flame-cells, has been found to have a constancy throughout the entire life cycle. Although it may be more highly elaborated in the marita than in the parthenita or the cercaria the fundamental pattern is essentially the same. Cort, Faust and La Rue have emphasized the importance of this system in determining the relationship of the cercarial, adolescarial and marital stages of the various species, as well as in reorganizing the classification of the entire class of trematodes. The excretory system is even now of great value in discovering the family, subfamily or generic positions of many larval forms and when its importance is more thoroughly recognized it will probably be useful even in evaluating various species to their proper positions in a natural system of classification. Unfortunately the excretory system can be studied satisfactorily only in living material and then only in species sufficiently transparent to permit the investigator to observe the various parts of the system in a fluke compressed under a microscopic cover-glass. Other structures of an ephemeral nature, such as the cephalic secretory glands of the cercaria, are also frequently serviceable in specific differentiation of the cercarial stage.

While an artificial system of classification has almost nothing to recommend it, a natural system based on fundamental relationships is of the greatest value, not only to the biologist but to the medical man, particularly to one engaged in epidemiological investigation. The emphasis placed on this phase of the subject of helminthology in manuals of parasitic infections is sufficient proof of the desire for a dependable system of classification which may be available particularly for recognizing the distinguishing characteristics of the various stages in the left cycle of trematodes parasitic in man, and for differentiating them from the very much larger number of species which are not parasitic in man. Fortunately for the student of medical zoölogy, the majority of the important trematode parasites which infect man have been made the subject of careful investigation, so that their life cycles are for the most part fairly well understood and their relationships to the class of trematodes as a whole fairly well determined.

The classification presented here is an adaptation of the older system, with rearrangements which are necessary because of recent investigations and additions which have to do particularly with the phases in the life cycle other than the marita. The most important single change necessitated by recent life-history studies is the removal of the blood flukes from the Distomata for inclusion in the Strigeata. The modified system presented here is necessarily incomplete and even yet probably not entirely natural, but is to be recommended as a step in the right direction because it takes into consideration all of the phases of the life cycle. It is also hoped that it will be more useful than the older, strictly morphological classification, since it furnishes more data for making differential diagnoses.

While the system has been elaborated only in those orders and suborders which contain flukes parasitic in man, a skeleton outline of the major divisions has been included for purposes of comparison. It must be understood, however, that no attempt has been made to include any of the large number of families or genera of trematodes such as occur in aquatic animals and birds, which are not of primary concern to the medical zoölogist.

CLASS TREMATODA RUDOLPHI, 1808.

Parasitic organisms; adults covered with a non-ciliated integument; ciliated epithelium confined to larvæ hatched from eggs; suckers almost always present; alimentary canal present except in sporocyst generation of Digenea.

Subclass I. Monogenea v. Beneden, 1858.

All species ectoparasitic or in excretory bladder or respiratory passages of host; organs of attachment one or more suckers, of which

those at the posterior end are powerfully developed; chitinous hooks and anchors almost always present; excretory pores anterior, double; development direct, with relatively simple metamorphosis. No representatives in man. Examples: *Gyrodactylus elegans* v. Nordmann, 1832, on skin and gills of fresh-water fish; *Polystoma integerrimum* (Froehlich, 1791), in amphibians.

Subclass II. Digenea v. Beneden, 1858.

Almost all species endoparasitic; organs of attachment consisting of one or two suckers, of which the anterior is always single and median; excretory pores posterior, double in parthenogenetic generations, single in "adult" (marital) individuals; development complex, with alternation of marital and parthenogenetic generations and alternation of hosts. All human trematodes belong to this group.

ORDER I. GASTEROSTOMATA ODHNER, 1905.

Mouth on mid-ventral surface; anterior sucker imperforate; intestine a simple sac; flame-cell pattern of the miracidium: 2 [1+1]; aquatic in distribution. No representatives in man. Example: *Bucephalus polymorphus* v. Baer, 1827.

ORDER II. PROSOSTOMATA ODHNER, 1905.

Mouth at or near anterior tip of body, surrounded by oral sucker. All of the human trematodes belong to this order.

Suborder I. Aspidocotylea[1] Monticelli, 1892.

Maritæ hermaphroditic; oral sucker absent or poorly developed in "adult" worms; ventral sucking organ a powerful adhesive disk or series of small suckers; intestine a simple sac; flame-cell pattern of the miracidium: 2 [1 + 1 + 1]. No human representatives. Example: *Aspidogaster conchicola* v. Baer, 1826.

Suborder II. Monostomata Zeder, 1800.

Maritæ hermaphroditic; no ventral sucker present; flame-cell pattern of the miracidium: 2 [1]; common in reptiles and birds, and occasionally parasitic in mammals. No human representative. Example: *Notocotylus quinqueserialis* Barker and Laughlin, 1911 (in American muskrat.)

[1] Ward (1918) writes of this group: "They were generally included under the **Monogenea** until Monticelli revived the original view that they should be regarded as an independent subdivision of equal rank intermediate between the **Monogenea** and the **Digenea**. Their very recent inclusion in the latter group has been well justified; yet even with that the striking differences noted . . . must be kept clearly in mind."

Suborder III. Strigeata La Rue, 1926.

Maritæ monecious or diecious; anterior sucker or attachment organ almost always present; one or more ventral acetabula usually present; cercarial stage with a bifid or forked tail; flame-cell pattern of the miracidium: 2 [1 + 1]; maritæ parasitic in gut or blood stream of vertebrates.

Superfamily I. Strigeoidea Railliet, 1919.

Maritæ hermaphroditic; body usually divided into two parts, the anterior being flattened, incurved, or cup-shaped, bearing the special organs of attachment, the posterior being more or less cylindrical, ovoid or conical, and containing the major portion of the genitalia; genital pore posterior; eggs operculate or with polar filament; cercariæ with a true oral sucker and a pharynx; adolescariæ (metacercariæ) in molluscs, leeches or the lower vertebrates; maritæ in vertebrates which feed on the second intermediate host.

Type Family STRIGEIDÆ Railliet, 1919.

With the characteristics of the superfamily. No species reported from man. Example: *Pharyngostomum cordatum* (Diesing, 1850), in intestine of cat.

Superfamily II. Schistosomatoidea Stiles and Hassall, 1926.

Maritæ monecious or diecious, blood-inhabiting flukes, without pharynx, with or without anterior and ventral acetabula; eggs non-operculate; cercariæ apharyngeal, with anterior sucker preoral in position, specialized as an organ of penetration; no encysted adolescarial stage; cercariæ on emerging from molluscan host enter definitive host through skin.

Type Family SCHISTOSOMATIDÆ Looss, 1899.

Sexes separate; anterior and ventral acetabula present; intestinal ceca reunite posteriorly to form a single stem; parasitic in hepatic portal blood of mammals and birds. Human representatives: *Schistosoma hæmatobium* (Bilharz, 1852); *S. bovis* (Sonsino, 1876); *S. japonicum* Katsurada, 1904; *S. mansoni* Sambon, 1907.

Suborder IV. Amphistomata (Rud., 1801) Bojanus, 1817.

Maritæ hermaphroditic; acetabulum highly developed, terminal or subterminal and posterior to the reproductive organs; eggs operculate; flame-cell pattern of the miracidium: 2 [1]; with or without a ventral pouch or disk.

Superfamily Paramphistomatoidea Stiles and Goldberger, 1910.

Maritæ with acetabulum caudo-terminal or subterminal; oral sucker and esophagus present; genital pore pre-equatorial; testes one or two, usually preovarial; vitellaria unpaired.

Family I. PARAMPHISTOMATIDÆ (Fischoeder, 1901), Stiles and Goldberger, 1910.

Maritæ without a ventral pouch. Three recognized subfamilies, of which a human representative is found in the

Subfamily Cladorchinæ Fischœder, 1901.—Body not divided into two parts; oral sucker provided with a pair of diverticula; testes two, deeply cleft. Human representative: *Watsonius watsoni* (Conyngham, 1904) Stiles and Goldberger, 1910.

Family II. GASTRODISCIDÆ Stiles and Goldberger, 1910.

Body of maritæ usually flattened and divided into a cephalic portion and a caudal portion, the latter in the form of a ventral sucking disk with many large papillæ. Human representative: *Gastrodiscoides hominis* (Lewis and McConnell, 1876) Leiper, 1913.

Suborder V. Distomata Zeder, 1800.

Maritæ hermaphroditic; oral and ventral suckers present; reproductive organs completely or largely posterior to ventral sucker; flame-cell pattern of the miracidium: 2 [1]. The majority of human trematodes belong to this group. This suborder contains many hundreds of species, which have been more or less satisfactorily placed in family groups. After careful consideration it has seemed advisable to designate superfamily groups for the families of species considered in this section.

Superfamily I. Fascioloidea Stiles and Goldberger, 1910, emend.

Medium to large flukes, producing large operculate eggs, which are oviposited in the early stages of segmentation. Miracidia developing and hatching in water; with x-type pigmented eye-spots; metamorphosing into sporocysts with or without cecum. Typically two or more generations of rediæ. Cercariæ large, robust, active, with simple tail; provided with abundant cystogenous material; encysting on vegetation or in fishes, which, when consumed by the definitive host, provide a means of transfer for the adolescariæ and for their development into mature worms. Excretory bladder primitively Y-shaped; lateral twigs and capillaries with terminal

flame-cells derived from an anterior and a posterior branch of the paired secondary collecting tubules; bladder and primary tubules frequently filled with excretory granules. Fundamental flame-cell pattern of marita: $2[(1 + 1) + (1 + 1)]$. Maritæ in small intestine and biliary passages of mammals. The superfamily consists of two families, **Fasciolidæ** Railliet, 1895 *sensu stricto* and **Brachycladiidæ** fam. nov. (= **Brachycladiinæ** Odhner, 1905). Human representatives are found in the type family **Fasciolidæ**, which includes forms living in the intestinal tract and biliary passages of land mammals, as distinguished from the **Brachycladiidæ**, which contains species resident in the biliary passages of sea mammals (Pinnipedia and Cetacea).

Type Family FASCIOLIDÆ Railliet, 1895.

Eggs very large, ellipsoidal, with thin shells; miracidia bilaterally symmetrical; cercariæ encysting on grass or roots of plants in moist meadows. Maritæ large, more or less flattened distomes, with elongate excretory bladder reaching nearly to the ovarian plane and with an abundant supply of lateral twigs and capillaries supplying the entire body; with ovary and testes greatly branched; with a short uterus, entirely in front of the ovary. The two recognized subfamilies both contain important human parasites.

Subfamily I. Fasciolinæ Stiles and Hassall, 1898.—Anterior tip of maritæ distinctly set off from the rest of the body; intestinal ceca profusely branched;[1] parthenitæ in species of Lymnæa; maritæ in biliary passages of herbivorous mammals. Human representatives: *Fasciola hepatica* (Linn., 1758); *F. gigantica* Cobbold, 1855. A third species, *F. jacksoni* (Cobbold, 1869) lives in the biliary passages of the Indian elephant. Another species, *Fascioloides magna* (Bassi, 1875), occurs in the biliary tracts of North American herbivores.

Subfamily II. Fasciolopsinæ Odhner, 1910.—Anterior tip of maritæ not set off from the rest of the body; intestinal ceca unbranched; parthenitæ in species of Planorbidæ; maritæ in intestine of the pig and man. Human representative: *Fasciolopsis buski* (Lankester, 1857). Other species of this genus which have been described from man are now considered to be identical with *F. buski*.

Superfamily II. Echinostomatoidea superf. nov.

Elongate, moderate-sized flukes, producing relatively large eggs with small opercular cap, and with embryos in early stage of development when oviposited. Miracidia with median eye-spot; develop-

[1] Odhner (1926) believes that *Protofasciola robusta* (Lorenz, 1880) Odh., 1926, which possesses unbranched testes and ovary, is the prototype of this group.

ing in water; probably metamorphosing directly into first generation rediæ. Cercariæ produced in second generation rediæ; with simple or marginally-fluted unbranched tails; typically with the number and arrangement of collar spines of the maritæ; encysting in their molluscan intermediate hosts, other invertebrates or vertebrates, or on vegetation, which, when consumed by the definitive host provide a means of transfer for the adolescariæ and for their development into mature worms. Excretory bladder a pouch-like structure, sometimes coiled back and forth, extending anteriad to the posterior limit of the posterior testis, where it receives the primary collecting tubules; lateral twigs and capillaries with terminal flame-cells derived from secondary and/or tertiary collecting tubules, which are characteristically filled with excretory granules. Fundamental flame-cell pattern of marita: $2\ [3 + (3)^n]$. Maritæ in intestinal tract of vertebrates. The species of this large and inadequately studied group are at present all placed in the

Type Family ECHINOSTOMATIDÆ Looss, 1902.

This has the characteristics of the superfamily. Of the five or more subfamilies which have been created for species of this family the forms parasitic in man are placed in the **Echinostomatinæ** and **Echinochasminæ.**

Subfamily I. Echinostomatinæ Looss, 1899.—Collar united ventrally by a ridge; cirrus sac not reaching posteriad beyond equator of acetabulum. Human representatives: *Echinostoma ilocanum* (Garrison, 1908); *E. malayanum* Leiper, 1911; *E. jassyense* (Léon and Ciurea, 1922); *E. sufrartyfex* (Lane, 1915).

Subfamily II. Echinochasminæ Odhner, 1910.—Collar not continuous across venter; collar spines interrupted on mid-dorsum; cirrus sac small. Human representative: *Echinochasmus perfoliatus* (v. Ratz, 1908).

SUPERFAMILY III. DICROCŒLIOIDEA SUPERF. NOV.

Small to moderate-sized flukes, flattened or cylindrical, producing small to medium-sized eggs, with rather heavy opercular cap, and with embryos fully developed when oviposited. Miracidia metamorphosing in the molluscan host into sporocysts. Xiphidiocercariæ with unbranched tails produced in second generation sporocysts; encysting in insect intermediate hosts or on vegetation, which, when consumed by the definitive host provide a means of transfer for the adolescariæ and for their development into mature worms. Excretory bladder Y-shaped, with relatively long stem; lateral twigs and capillaries with terminal flame-cells arising directly from the lateral pair of primary collecting tubules. Fundamental flame-cell pattern of marita: $2\ [(1 + 1 + 1) + (1 + 1 + 1)]$. This

superfamily includes the following families: **Dicrocoeliidæ** (Looss, 1907); **Brachycoeliidæ** S. J. Johnston, 1912; **Plaigorchidæ** Lühe, 1901, and **Lissorchidæ** Poche, 1926. Human representatives are found in the

Type Family DICROCŒLIIDÆ (Looss, 1907.)

Maritæ leaf-like or cylindrical, with testes in front of the ovary. Eggs relative small, with thickened shoulder into which the operculum fits; miracidia bilaterally symmetrical, without eye-spot; cercariæ undescribed, but undoubtedly encysting in or about moist vegetation; maritæ in biliary (and occasionally pancreatic) passages of vertebrates. Excretory bladder with a long stem. Fundamental flame-cell pattern of marita: $2\,[(2 + 2 + 2) + (2 + 2 + 2)]$. Human representatives: *Dicrocœlium dendriticum* (Rudolphi, 1819), and possibly *Eurytrema pancreaticum* (Janson, 1889).

Superfamily IV. Heterophyoidea superf. nov.

Small oval, pyriform or elongate flukes, producing small, rather thick-shelled eggs, having bilaterally symmetrical embryos, which are fully developed when oviposited. Miracidia passively entering the molluscan hosts and metamorphosing into sporocysts. Cercariæ developing in rediæ; possessing a pair of pigmented eye-spots, well-developed cephalic secretory glands and specialized oral spines, as well as marginally-fluted tails; encysting in animal tissues, which, when consumed by the definitive host, provide a means of transfer for the adolescariæ and for their development into the mature worms. Excretory bladder Y-shaped; lateral twigs and capillaries with terminal flame-cells derived directly from the lateral pair of collecting tubules. Fundamental flame-cell pattern of marita: $2\,[(1 + 1) + (1 + 1)]$. Maritæ in the intestinal tract of vertebrates. This superfamily includes the type family **Heterophyidæ** Odhner, 1914, and possibly the family **Lecithodendriidæ** Odhner, 1910, as well as the subfamilies **Microphallinæ** Ward, 1901 and **Gymnophallinæ** Odhner, 1905, although the allocation of these latter groups to this superfamily cannot be definitely made without further information regarding their life histories. Human representatives are found in the

Type Family HETEROPHYIDÆ Odhner, 1914.

Parthenitic generations utilizing species of Melania and Bithynia; cercariæ encysting in fresh-water fishes; maritæ provided with a genital sucker; living in intestinal mucosa of birds and mammals. Fundamental flame-cell pattern of marita: $2\,[(3 + 3) + (3 + 3)]$. All known species appear to be facultative parasites of man but

species from the following four subfamilies are the only ones reported from the human host.

Subfamily I. Heterophyinæ Ciurea, 1924.—Acetabulum and genital sucker of adult on ventral surface, well developed; testes two. Human representatives: *Heterophyes heterophyes* (v. Siebold, 1852) [= *H. nocens* Onji and Nishio, 1915]; *H. katsuradai* Ozaki and Asada, 1925.

Subfamily II. Metagoniminæ Ciurea, 1924.—Acetabulum well-developed, situated in genital sinus; genital sucker atrophied; testes two. Human representative: *Metagonimus yokogawai* Katsurada, 1912.

Subfamily III. Centrocestinæ Looss, 1899.—Acetabulum pre-equatorial, in genital sinus or projecting on ventral surface; genital sucker in genital sinus, undergoing atrophy, with a fan-like complement of rodlets; testes two. Human representatives: *Stamnosoma armatum* Tanabe, 1922; *S. formosanum* Nishigori, 1924.

Subfamily IV. Monorchotreminæ Nishigori, 1924.—Genital sucker fused in part with the ventral sucker, surrounded by a half-circlet of rodlets; single large testis in place of usual two. Human representatives: *Monorchotrema taihokui* Nishigori, 1924; *M. taichui* Nishigori, 1924.

Superfamily V. Opisthorchoidea superf. nov.

Flattened transparent leaf-like flukes of moderate size, producing small operculate eggs with thickened shoulder, and containing fully developed embryos when oviposited. Miracidia without eye-spots, bilaterally asymmetrical; metamorphosing into sporocysts in species of Bithyniidæ and possibly Melaniidæ. Cercariæ developing in rediæ (second generation parthenitæ); possessing pigmented eye-spots, well-developed cephalic secretory glands and having marginally-fluted tails, but lacking specialized oral spines; encysting in fresh-water fishes, the consumption of which furnishes a means of transfer for the adolescariæ to the definitive host. Genital pore of maritæ preacetabular, without specialized sucker. Excretory bladder Y-shaped, with unequal arms and with a median S-shaped anterior pouch-like extension; lateral twigs and capillaries with terminal flame-cells derived in one continuous series from the pair of ascending secondary collecting tubules. Fundamental flame-cell pattern of marita: $2 [2 + 2 + 2 + 2 + 2 + 2]$. All of the known species belong to the

Type Family OPISTHORCHIDÆ Lühe, 1901.

This type family has the characters of the superfamily. Human representatives live in the biliary passages of vertebrates. They are grouped in the following two subfamilies:

Subfamily I. Opisthorchinæ Looss, 1899.—Excretory bladder long, triangular, with median anterior blind tubule; uterine coils postacetabular, confined between ceca. Human representatives: *Opisthorchis felineus* (Rivolta, 1884); *O. viverrini* (Poirier, 1886): *O. noverca* Braun, 1902, *Clonorchis sinensis* (Cobbold, 1875).

Subfamily II. Metorchinæ Lühe, 1909.—Excretory bladder short; uterine coils partly overlap ceca and extend preacetabulad. Human representative: *Pseudamphistomum truncatum* (Rud., 1819).

Superfamily VI. Troglotrematoidea superf. nov.

Relatively small fleshy ovate flukes, producing moderately large eggs, with a broad opercular cap and slightly thickened shoulder, and containing embryos in the early stage of development at the time of oviposition. Miracidia without eye-spots, bilaterally symmetrical; utilizing Melaniidæ and possibly other species of molluscs in which to metamorphose into first generation parthenitæ. Cercariæ produced in rediæ (second generation parthenitæ); small, delicate larvæ, with oral stylet and short, knob-like tail; encysting in arthropods, which, when consumed by the definitive host, afford a means of transfer for the adolescariæ. Maritæ encysted, typically in pairs, in the respiratory and connective tissues of higher vertebrates. Excretory bladder inverted triangular or with a short posterior shank, at times (in *Paragonimus*) with a long median tubular pouch arising near the genital pore and extending far anteriad; lateral twigs and capillaries with terminal flame-cells derived directly from the lateral pair of primary collecting tubules. Fundamental flame-cell formula of marita: $2\,[(3 + [3 + 3] + [3 + 3]) + ([3 + 3] + [3 + 3] + 3)]$. The few known species belong to the

Type Family TROGLOTREMATIDÆ Odhner, 1914.

This type family has the characters of the superfamily. Human representative: *Paragonimus westermani* (Kerbert, 1878). The name *Paragonimus ringeri* (Cobbold, 1880) is considered to be a synonym of *P. westermani.*

Superfamily VII. Hemiuroidea nom. nov. (Hemiurida Dollfus, 1923, emend. Poche, 1926).

Medium to large flukes, usually oval and flattened, producing small to medium-sized eggs, which contain, when oviposited, fully developed, bilaterally symmetrical embryos. Cercariæ cystophorous in type, produced in rediæ; utilizing various insects as second intermediate hosts. Maritæ in the intestines and other tissues of fishes. Excretory bladder Y-shaped; lateral twigs and capillaries with terminal flame-cells derived directly from the lateral pair of primary collecting tubules, which have an anterior transverse anastomosis.

Fundamental flame-cell formula of marita: 2 [(2 + 2 + 2) + (2 + 2 + 2)]. In addition to the type family, **Hemiuridæ** Lühe, 1901, the following families are included in this superfamily: **Halipegidæ** Poche, 1926; **Isoparorchidæ** Poche, 1926; **Xenoperidæ** Poche, 1926 and **Azygiidæ** Odhner, 1911. Accidental human infection has resulted from ingestion of one species of the family **Isoparorchidæ**.

Family ISOPARORCHIDÆ Poche, 1926.

These are conspicuously flattened forms normally living in the swim-bladder of fishes. Consumption of raw or insufficiently cooked infested fish may occasion accidental parasitism in the human intestine. Species reported from man: *Isoparorchis trisimilitubis* Southwell, 1914.

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CHAPTER X.

TREMATODE PARASITES OF THE BLOOD SYSTEM.

Superfamily Schistosomatoidea Stiles and Hassall, 1926.

Introduction.—The trematode parasites of the blood are commonly spoken of as blood flukes. They are characterized by the absence of a pharynx and by having non-operculate eggs (Fig. 14). The fork-tailed cercariæ have an anterior sucker preoral in position, specialized as an organ of penetration. On erupting from the molluscan host the cercariæ enter the definitive host through the skin.

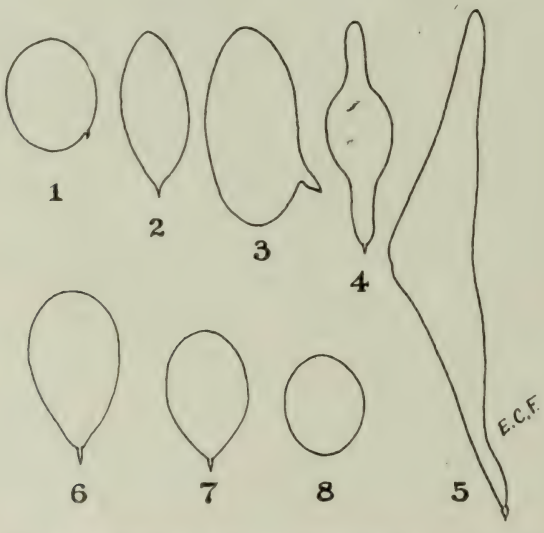


Fig. 14.—Eggs of the species of blood flukes described from mammals. 1, *Schistosoma japonicum;* 2, *S. hæmatobium;* 3, *S. mansoni;* 4, *S. bovis;* 5, *S. spindale;* 6, *S. bomfordi;* 7, *S. indicum;* 8, *Schistosomatium pathlocopticum.* (Drawn to the same scale; compiled from various sources.)

Some members of this superfamily are parasitic in the lower vertebrates, including fishes and turtles, while species more nearly related to the human blood flukes are common in birds. All of the species which have been described from mammals, with the exception of *Schistosomatium pathlocopticum* Tanabe, 1923, for which laboratory rats and mice were found to be suitable experimental hosts, belong to the genus *Schistosoma* Weinland, 1858. The eight species of this

genus which have been reported from mammals are as follows: *Schistosoma hæmatobium* (Bilharz, 1852); *S. bovis* (Sonsino, 1876); *S. japonicum* Katsurada, 1904; *S. mansoni* Sambon, 1907; *S. spindale* Montgomery, 1906; *S. indicum* Montgomery, 1906; *S. bomfordi* Montgomery, 1906, and *S. turkestanicum* Skrjakin, 1913. The first four of these species are human parasites, while *S. spindale* has possibly been found in human infections.

THE HUMAN BLOOD FLUKES OR SCHISTOSOMES.

Family SCHISTOSOMATIDÆ Looss, 1899.

General Considerations.—The human blood flukes, like the other members of the family **Schistosomatidæ** to which they belong, live

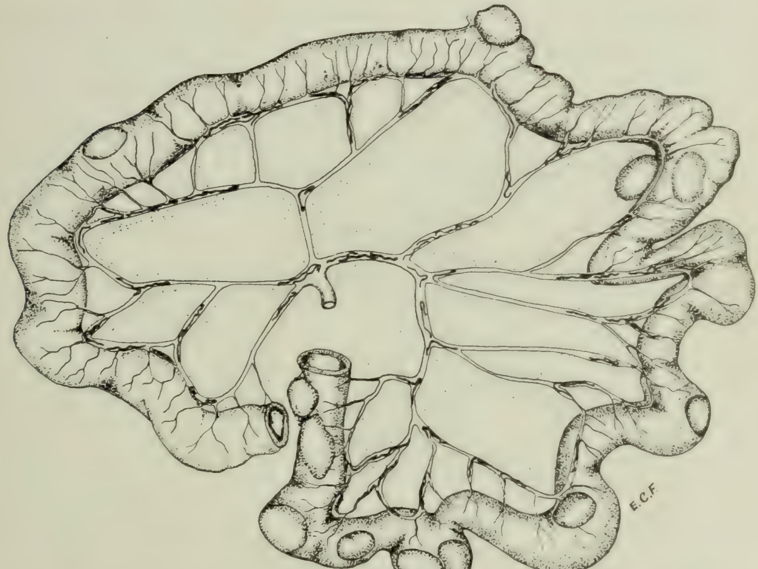


FIG. 15.—Loop of small intestine and attached mesentery of rabbit, showing schistosomes (*Schistosoma japonicum*) in the veins. (Original.)

in the portal blood system. They are unisexual individuals of which the male is the larger, more robust, and the female the more slender and delicate individual. The male is further characterized by having the lateral margins of its body curved ventrad so as to form a long groove or trough, in which the female lies during a considerable part of her life. This groove is called the *gynecophoral canal.* During life the worms most commonly reside in the extrahepatic portion of the portal system (Fig. 15), being attached by

their suckers to the intima of the veins. Here they feed on the rich blood coming from the intestines. Here insemination of the females by the constantly attending males takes place. And here the females lay their eggs. In the case of *Schistosoma japonicum*, *S. mansoni*, and probably *S. bovis*, the worms are most usually found in the mesenteric radicles; on the other hand *S. hæmatobium* has a predilection for the vesical, pubic and uterine plexuses, into which the female worm wanders to lay her eggs. In either case the ovipositing female extends the anterior part of her body into the small veins and venules immediately adjacent to the wall of the intestine or of the bladder, so that the eggs are deposited in the smallest venules and in the capillaries. Some of these eggs are carried along with the blood stream into the liver, where they are extravasated into the tissues of this organ and set up inflammatory processes. However, a considerable number, probably a major portion of the eggs, remains in the congested mesenteric capillaries which are blocked by the bodies of the female worms. Sooner or later these eggs are extruded into the wall of the intestine or bladder. Some remain in the tissues while others are evacuated into the lumen of the organ and pass out with the feces or urine. The disease produced by those species whose eggs are evacuated through the tissues of the gut is known as intestinal schistosomiasis; that produced by *S. hæmatobium* is commonly spoken of as urinary or vesical schistosomiasis.

Life Cycle of the Human Blood Flukes.—The eggs of the blood fluke are immature when they are laid by the mother worm. By the time they have passed through the tissues and are recovered from the feces or urine they are usually mature and the vibrating cilia of their epithelium can be observed through the shell wall. On dilution of the exudate such as occurs when feces or urine reaches canal water, the shell spits open and the larva (miracidium) emerges. However, if the exudate remains undiluted for some time, particularly in warm climates, the larva within the shell is killed by the toxic products present or soon developed in the medium. The miracidium once set free in a favorable isotonic environment is able to swim about as a free-living organism for some hours, utilizing the foodstuffs which it has received from the mother worm. In the event that it finds itself in the immediate vicinity of the molluscan host to which it is physiologically adapted, it attacks and proceeds to penetrate the soft parts of this mollusc. The miracidium possesses no spines or other armature which it can use for this purpose, but the vigorous beating of its cilia once having brought it in contact with a mucus-secreting surface of the appropriate snail, droplets of a viscous histolytic ferment which have been elaborated in special glands of the larva are poured out rapidly and soon effect an entrance into the soft tissues of the host, so that

within a half hour or an hour after the attack has been undertaken, penetration has usually been secured. Some schistosome miracidia enter *via* the head or foot; others gain entry through the gill filaments of the snail.

The intra-molluscan phase of the life cycle involves the gradual migration of the larva from the oral toward the apical end of the host, at first through artificially produced lumina, later *via* natural lymph sinuses. Meanwhile the larva has become modified into a simple sacculate sporocyst, which, in turn, produces parthenogenetically within its brood cavity a second generation of sporocysts, more elongate than the mother sporocysts. By this time the parasitic progeny have reached the inter-hepatic lymph spaces, where they are bathed in a highly nutritious medium. The second generation sporocyts then produce parthenogenetically within their brood cavities a new generation of individuals, which soon become differentiated into furcocercous cercariæ. They are the larvæ of the third generation. The period required for the intramolluscan phase of the life cycle (*e. g.*, from the entry of the miracidia until the cercariæ are mature) varies under natural conditions from five to seven weeks. Upon the cercariæ becoming mature they erupt from the parent sporocyst, break through the distended tissues of the snail and emerge tail first through the opening between the snail and the shell. This occurs only in case the snail is in the water.

The cercaria, after issuing forth into the free-living environment, swims about vigorously for some time and then comes to rest at the bottom or attached to the under side of the surface of the water. It is alternatively motile and resting for forty-eight to seventy-two hours, after which times it dies unless an opportunity is offered for its transfer to a mammalian host. In heavily endemic areas it is usual to find 1 to 10 per cent of the susceptible molluscan hosts infected with the sporocysts and developing cercariæ of the human blood flukes.

Entry into the definitive host is an active process for the cercaria. The exact means by which this is effected has not been satisfactorily demonstrated, but a susceptible mammal, all or part of whose body comes in contact with "infected water" (*e. g.*, water containing viable cercariæ) is liable to infection (see Figs. 16 and 17). It is believed that very few if any schistosome cercariæ penetrate the mammalian skin except from contact with a surface film of water. Possibly the largest amount of infection occurs on the extremities of the host, which are alternately immersed and then withdrawn from the water, so that the cercariæ remain in the film of water covering the skin, which soon begins to evaporate. In order to avoid death from desiccation the cercariæ attack and penetrate the skin. This penetration is effected in a manner similar to that utilized by the miracidium in securing entry into the molluscan host, namely by

the discharge of histolytic ferments at the head end of the cercaria, which digest away and effect an entrance through the host tissue. Even though the cercaria is armed with abrasive as well as digestive

Fig. 16.—Common method of incurring infection with *Schistosoma hæmatobium* and *S. mansoni* in Egypt. (After Faust and Meleney, Am. Jour. of Hygiene.)

apparatus its entry requires hours as compared with the relatively rapid entry of the miracidium into the snail. This is due to the much greater resistance of the mammalian skin.

Fig. 17.—Common method of incurring infection with *Schistosoma japonicum* in China. (After Faust and Meleney, Am. Jour. of Hygiene.)

During the process of penetration the cercaria discards its tail, so that only the body of the cercaria actually enters the mammal. The postcercarial or adolescarial stage of the mammalian blood fluke is known as a *schistosomulum*. After a period of about twenty hours of active digestion through the skin layers the schistosom-

ulum reaches the peripheral bloodvessels. On entering a venule its active penetration is brought to an end. Thereafter it is carried through the venous circulation to the lungs, where the majority of

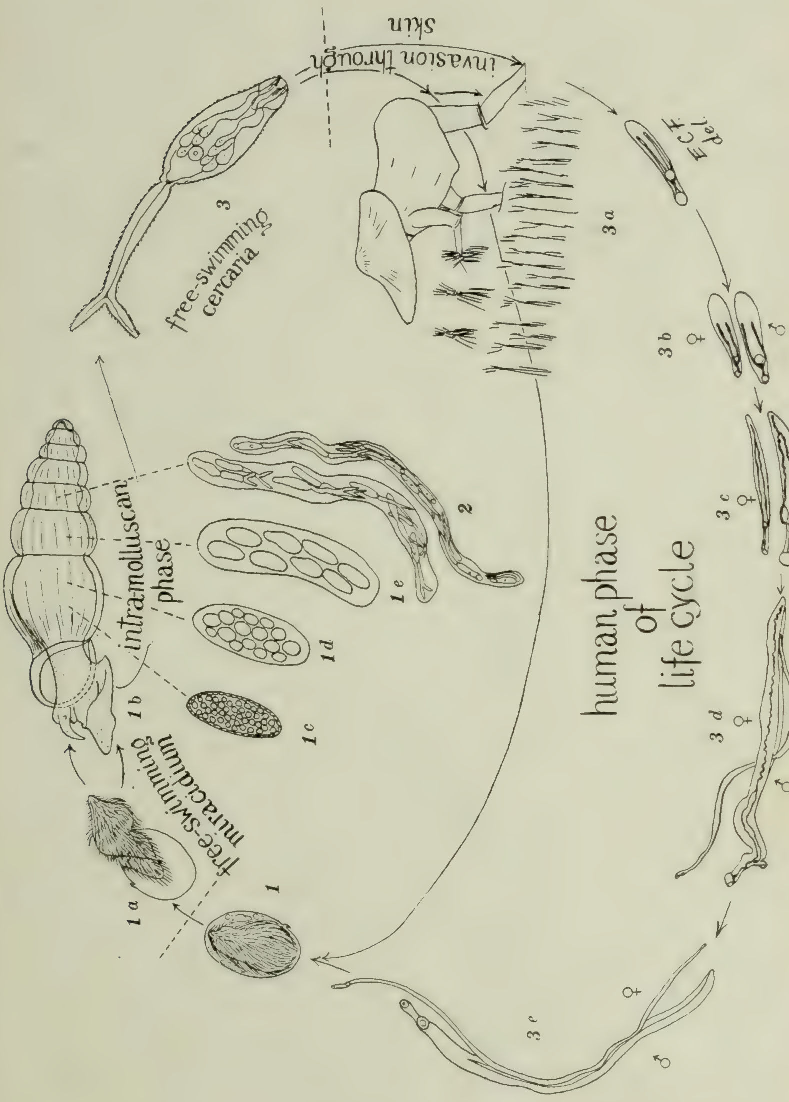


FIG. 18.—Life cycle of a human blood fluke, *Schistosoma japonicum*. (Original.)

the migrating worms pass through the pulmonary capillaries and enter the arterial circulation. Although there is probably no selective migration, the majority of the young worms pass into the

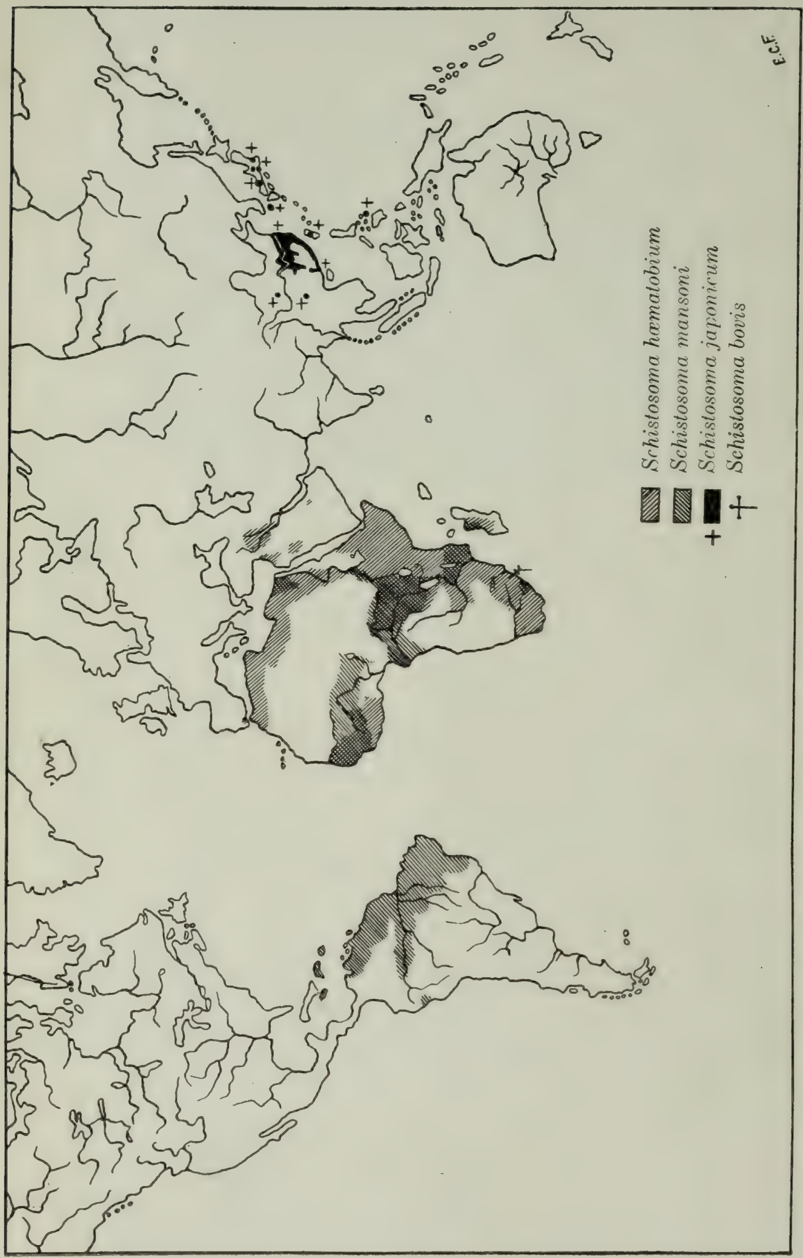


FIG. 19.—Map showing the distribution of the human schistosomiases. (Compiled from various sources.)

arteries feeding the abdominal viscera. Of this group apparently only those which reach the mesenteric arteries and pass through to the mesenteric veins are able to develop further. Those reaching the renal and peripheral circulation and probably those in other foci soon die and thus come to assume the rôle of foreign protein emboli at these sites.

The schistosomula first begin to feed after they arrive in the portal vessels, the food consisting primarily of blood corpuscles. During this active period of growth the young worms live for the most part in the intra-hepatic portion of the vessels, where the males and females soon begin to show recognizable differences, the male becoming broad and stout and the female long and slender. Upon arriving at sexual maturity the worms migrate out into the mesenteric radicles, where they mate and the females begin to lay eggs. From twenty-eight to thirty-five or more days after the cercariæ penetrate the skin eggs are first recovered from the excreta. The accompanying diagram (Fig. 18) of the life cycle of *Schistosoma japonicum* is typical for the group.

Geographical Distribution of the Human Schistosomes.—Three of the species of human blood flukes, *Schistosoma hæmatobium, S. mansoni* and *S. bovis,* appear to have originated in the Nile Valley, from whence they have been disbursed. On the other hand *Schistosoma japonicum* is confined to the Far East. It is altogether probable that the Yangtze Valley was the original home of this parasite. *Schistosoma hæmatobium, S. mansoni* and possibly *S. bovis* have become adapted to related groups of non-operculate gasteropods as their intermediate hosts. In South Africa evidence points to the view that the two former species of flukes utilize the same species of host (Physopsis). The species of snails (Bulinus, Physopsis) in which *S. hæmatobium* develops are relatively common throughout Africa, the adjacent region of Western Asia, and parts of Southern Europe, while the typical molluscan host (Planorbis) of *S. mansoni* is quite cosmopolitan in its distribution. The species of operculate amphibious snails which *S. japonicum* utilizes for the intra-molluscan phase of its life cycle are peculiar to certain areas of the Far East. Examination of the accompanying map (Fig. 19) shows that schistosomiasis hæmatobia and schistosomiasis japonica are practically coextensive with the distribution of the molluscan hosts utilized by the worms causing these respective infections, while schistosomiasis mansoni has spread only to parts of Africa and the northern part of South America and the adjacent Caribbean islands. The only definite human records of schistosomiasis bovis are from Natal, South Africa, but it seems altogether likely that the terminal-spined ova found by Chesterman in the stools of patients in West Africa suffering from severe intestinal schistosom-

iasis were those of *S. bovis*, as were those found by Christophers and Stephens in a Madras Indian with a history of previous residence in Natal. Thus schistosomiasis japonica is highly restricted in its distribution, in accordance with the distribution of its molluscan host; schistosomiasis hæmatobia is relatively unrestricted and schistosomiasis mansoni is potentially cosmopolitan in its distribution. However, the actual and potential distribution of these latter two species are still too little known to justify any sweeping statement.

CHAPTER XI.

THE HUMAN BLOOD FLUKES.

Genus Schistosoma Weinland, 1858.
(genus from σχιστός, split, and σομα, body).

Schistosoma hæmatobium (Bilharz, 1852) Weinland, 1858.—(The causative organism of vesical schistosomiasis).

Synonyms.—*Distoma hœmatobia* Bilharz, 1852; *Gynœcophorus hœmatobius* (Bilharz, 1852) Dies., 1858; *Bilharzia hœmatobia* (Bilharz, 1852) Cobbold, 1859; *Bilharzia magna* Cobbold, 1859; *Thecosoma hœmatobium* (Bilharz, 1852) Moq.-Tandon, 1860; *Bilharzia capensis* Harley, 1864; *Bilharzia œgyptiaca* Miyagawa, 1924.

Historical.—Although there is evidence that vesical schistosomiasis was present in Egypt in ancient times and although the various armies of occupation of this country within modern times, particularly the French in 1799–1801, suffered from the disease, the causative organism, *Schistosoma hœmatobium*, was not discovered until 1851, when Bilharz recovered the worms from the mesenteric veins of a native of Cairo. The first record of the finding was published in 1852. Some time later Bilharz found that this organism was associated in a causal way with hematuria, which was common in the native fellaheen population, and with the presence of eggs in the urine. In 1864 Harley showed that the hematuria of South Africa was due to a blood fluke, which he called *Bilharzia capensis,* to distinguish it from the North African variety, because he found only terminal-spined eggs in the urine of his cases, whereas Bilharz and his colleague Griesinger had figured both terminal- and lateral-spined ova. Both Harley (1864) and Cobbold (1864) believed that some mollusc served as the intermediate host of the fluke, but the efforts of these workers, as well as of Sonsino (1874–1895), Lortet and Vialleton (1894–1905) and Looss (1894–1914) were all unsuccessful in throwing much light on the phase of the life cycle outside of the definitive host. Meanwhile Allen (1888), Brock (1894) and others had come to the conclusion on epidemiological grounds that infection was incurred through the skin, although, as we now know, their belief that the miracidium was the invading stage, was incorrect. As early as 1893 Manson suggested that the vesical and intestinal types of infection were due to two different species. In support of this belief Sambon (1907) proposed

a new species name, *Schistosoma mansoni*, for the worm which produced the lateral-spined egg. In 1915 Leiper, who had previously visited Japan and had confirmed the experimental findings of Miyairi, that a mollusc was the intermediate host of *Schistosoma japonicum*, restudied the problem in Egypt and by a series of convincing experimental tests, proved that two types of molluscs were involved in the Egyptian infection and that those worms which developed in Bulinus (Isidora), on maturity in mammals, produced terminal-spined ova, while those which developed in Planorbis produced lateral-spined ova in their definitive host. Leiper also showed that the adult worms of these two types were morphologically different, thus confirming Manson's and Sambon's hypothesis, and demonstrated that those producing terminal-spined eggs (*S. hæmatobium*) were the cause of vesical schistosomiasis, while those producing lateral-spined eggs were the cause of intestinal schistosomiasis. Following this McDonagh (1918) first advocated and Christopherson (1918) introduced on a large scale the use of tartar emetic in the treatment of schistosomiasis. In recent years Khalil and others have combined epidemiological studies with campaigns for prevention and treatment of the infection.

Geographical Distribution of Schistosoma Hæmatobium.—Schistosomiasis hæmatobia is extensively distributed throughout Africa (Fig. 19). It is present in a considerable portion of the population of the Nile Valley, where the fellaheen are heavily infected. Ferguson (1911) found the worms *postmortem* in 40 per cent of the male subjects, while Khalil (1924) states that "about 70 to 80 per cent of the total population of Egypt are infected with bilharziasis," of which infection with *S. hæmatobium* constitutes more than 90 per cent of the whole. He believes that the disease is on the increase in Egypt, due to the "continuous construction of small irrigation canals and drains throughout the country," which afford a favorable habitat for the molluscan hosts. The infection is common in the Sudan, Abyssinia, and along the entire east coast of Africa from Somaliland to the Cape, being particularly heavy in the lower Zambesi and along the coast of Natal. In Central Africa it extends southward from the Sudan through Uganda, Tanganyika and Nyasaland to Rhodesia. In West Africa its known distribution includes the Lake Chad district, the Upper Niger, and the coast from Senegal south to the Congo and possibly as far as Angola and the Cameroons. Along the coast of North Africa it extends from Egypt to Morocco. It is known to be endemic in southern Portugal and has been reported from Greece and the isle of Cypris. In Western Asia it occurs in Palestine, Syria, parts of Arabia, Mesopotamia and Syria.

It is found on the islands of Madagascar, Mauritius and Reunion. It is also stated to have become established in Australia, where apparently autochthonous cases have been discovered.

Structure and Life Cycle of Schistosoma Hæmatobium.—The first careful study of the adult worms and of the miracidium was that of Looss (1896). The worms, which are diecious, live in the portal blood and in the vesical plexuses. In ordinary infections the males and females are about equal in numbers. The male is the shorter, stouter individual, while the female is delicate and elongate (Fig. 20). During the greater part of its productive life the female

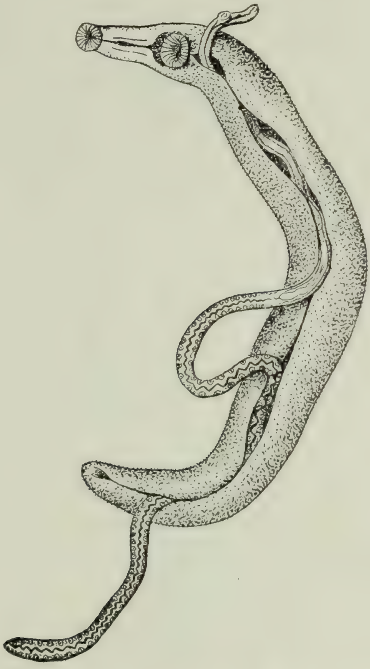


FIG. 20.—Male and female specimens of the human blood fluke (*Schistosoma hæmatobium*). × 12. (After Looss.)

lives in the gynecophoral canal of the male, which is formed by the infolding of the ventral side of the male's body posterior to the ventral sucker. Both sexes possess an anterior and a ventral sucker, which are situated close together at the anterior extremity of the worm. In the female these suckers are nearly equal, but in the male the ventral one is considerably larger and more muscular. The integument of the male is covered with minute papillæ, which in the female are confined to the anterior and posterior extremities. In both sexes the esophagus reaches to the anterior margin of the ventral sucker, where it bifurcates to form the ceca. There is no pharyngeal sphincter but the esophagus is surrounded by glands (see Fig. 22). The paired ceca extend to the middle of the body, where they join one another to continue posteriad as a single zigzag serpentine trunk which ends blindly near the posterior end of the

body. The nervous system is not essentially different from that of other trematodes. The excretory system consists of a small median posterior bladder, with a pair of collecting tubules having equal anterior and posterior tributaries.

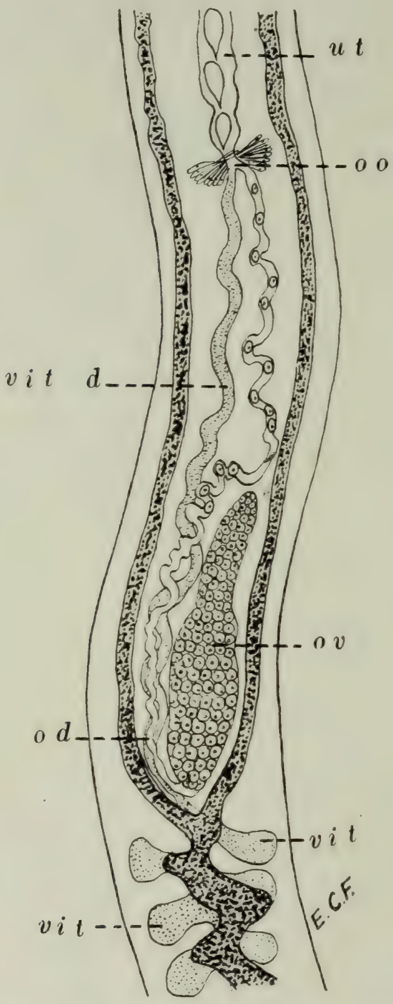


Fig. 21.—Primary and secondary reproductive organs of female *Schistosoma hæmatobium.* (Original.)

Differential Characteristics of Male and Female Worms.—The female is a slender worm, measuring about 20 mm. in length by about 0.25 mm. in transverse diameter. Her body is grayish or pinkish-creamy in color while the gut is a distinct reddish-black,

like that of a leech, due to inclusion of degenerating red blood cells of the host. There is a full complement of female reproductive organs (Fig. 21). The ovary (*ov*) is an elongate object, club-shaped anteriorly and rounded posteriorly. It is situated in the fork where the two ceca join posteriorly. From its posterior face there originates an oviduct (*od*), which immediately bends forward and after travelling a slightly tortuous course opens into the oötype (*oo*). From the posterior end of the worm in alternate positions as far forward as the fork of the ceca there are vitellaria (*vit*) with a single median vitelline duct, which passes under the junction of the ceca and proceeds forward in a course parallel to the oviduct, finally emptying into the oötype. From the anterior face of the oötype the system is continued as the uterus (*ut*), which opens to the exterior through a small genital pore just behind the acetabulum. Naked egg cells from the ovary work their way forward through the oviduct until they reach the oötype, where they are fertilized, the vitelline cells are added, the shell is secreted and the fully formed egg is pushed forward into the uterus through a sphincter which regulates the mechanism. The eggs in the uterus nearest the oötype are the least mature, while those nearest the genital pore are the most mature of the uterine eggs. From 20 to 30 of these eggs may be present in the uterus at one time.

The male worm measures from 10 to 15 mm. in length by about 1 mm. in greatest diameter when its sides are in the characteristic incurved position. There are integumentary spines on the suckers and characteristic papillæ over the greater part of the body, particularly on the inner surface of the gynecophoral canal. The reproductive organs (Fig. 22) consist of four or five testes (*t*), each with an efferent duct leading into a vas deferens, which enlarges to form a seminal vesicle, before opening through the genital pore (*gp*), which is situated just behind the ventral sucker. There is no penial organ or other accessory male sexual apparatus.

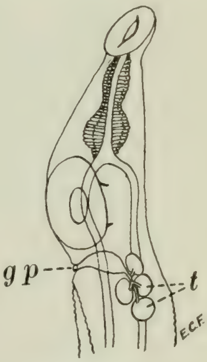


FIG. 22.—Anterior end of male *Schistosoma hæmatobium*, showing reproductive organs. (Original.)

Adult worms of this species may at times be found in the intrahepatic portion of the portal vessels, or in the splenic vein. More usually, however, they reside in the tributaries of the inferior mesenteric veins, including the hemorrhoidals and particularly the vesical plexuses. Once the worms reach these foci, according to Fairley and Manson-Bahr, "the paired worms travel against the blood stream to the furthermost possible point, where the female leaves her partner, and, being of a smaller diameter, is able by means of her

suckers to progress until she stretches the smaller venules to their utmost. The eggs are now deposited with their spines directed posteriorly. The female then withdraws so that the egg she has deposited lies a little in front of the anterior sucker. The process is then repeated. When after the deposition of an egg, the worm retires, the vein contracts to its original dimensions, embracing the egg, and the returning blood drives the spine into the wall of the vein." Thus by stasis of the smaller vessels and by digestive ferments, elaborated by the miracidium within the egg, which ooze out through minute pores in the egg shell, the vessels are ruptured and the eggs escape into the tissues. The majority of these finally escape into the lumen of the bladder and are passed in the urine.

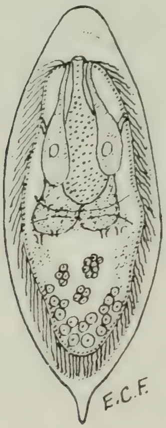


FIG. 23.—Mature egg of *Schistosoma hæmatobium.* × 400. (Original.)

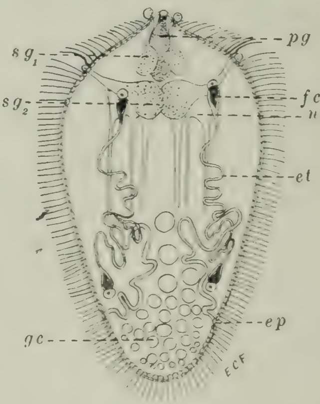


FIG. 24.—Miracidium of *Schistosoma hæmatobium.* *ep*, excretory pore; *et*, excretory tubule; *fc*, flame-cell; *gc*, germ cell; *n*, nerve center; *pg*, primitive gut; sg_1, anterior salivary gland; sg_2, posterior salivary gland complex. × 400. (Original.)

In a small percentage of cases terminal-spined eggs are also extruded through the wall of the rectum. At times worms reach the iliac vein, the inferior vena cava or the lungs. Eggs are not uncommonly found in the lungs, and occasionally in the brain and in other atypical foci.

The Egg and the Miracidium.—The eggs which are passed in the urine (Fig. 23) usually contain mature viable miracidia. The shells are oval at one end (the anterior end) and conical at the other, tapering to a distinct spine. They measure over all from 120 to 160 μ in length and have a transverse diameter of 40 to 60 μ. They are light yellowish-brown in color and fairly transparent. On dilution of the freshly passed urine with 4 parts or more of water the shell splits open and the miracidium emerges. Normal hatching

occurs in a non-toxic isotonic medium such as that of the canals, irrigation ditches and ponds in endemic areas. Hatching will not occur in undiluted urine. If the urine remains undiluted for some hours the larva becomes less and less active and finally dies. The emergent miracidium of this species (Fig. 24) is typical of the human schistosome group, possessing a ciliated epithelium, two-paired groups of secretory glands (*sg*), one pair opening at the anterior end and one on the antero-lateral margins, a primitive gut (*pg*), a nerve center (*n*), two pairs of flame-cells (*fc*) with tubules (*et*) opening through a single pore (*ep*) on the postero-lateral margins, and germ cells (*gc*) which arise from the germinal epithelium at the posterior

FIG. 25.—Molluscan hosts of *Schistosoma hæmatobium* in Africa. *A*, *Bulinus (Isidora) contortus* from Egypt, *B*, *Physopsis africana* from Natal, *C*, *Physopsis globosa* from W. Africa. Natural size. (Original photographs.)

end of the larva and are proliferated into the brood cavity. The miracidium of *S. hæmatobium* is distinguishable from that of *S. japonicum* (see Fig. 45) both morphologically and physiologically. The antero-lateral secretory glands of the larva of *S. hæmatobium* are clearly differentiated into two clusters, while in *S. japonicum* these clusters are fused. In *S. hæmatobium* miracidia there is a non-ciliated band completely encircling the organism in the plane of the excretory pores, while in *S. japonicum* the cilia are interrupted only in the immediate vicinity of the pores. The miracidia of *S. hæmatobium* are equally distributed throughout various levels of the water, while those of *S. japonicum* usually collect in the top 2 or 3 cm. of water. Similar detailed studies have unfortunately not been

made for the miracidium of *S. mansoni*. These free-living miracidia are able to swim about actively for a period of twenty-four to thirty-two hours. During this interval they are able to attack and penetrate the appropriate molluscan host. The type host in the case of *S. hæmatobium* is a non-operculate snail (Fig. 25) of the genera Bulinus (Isidora) and Physopsis, but species of Planorbis have apparently also been incriminated. In Egypt the appropriate hosts include *Bulinus* (*Isidora*) *dybowski, B contortus* and *B innesi;* in South Africa, *Physopsis africana;* in Portugal and Morocco, *Planorbis metidjensis* var. *dufouri*. Furthermore, Dye claims that in Northern Nyasaland *Melania nodocincta* is involved, but this requires confirmation, since melaniid snails are not even distantly related to the typical host species.

Intramolluscan Phase of the Life Cycle.—Within the mollusc the miracidium is transformed into a smooth-walled sporocyst, which, in turn, produces a second batch of sporcysts. Meanwhile the parasitic progeny migrate through the lymph spaces of the mollusc and establish themselves in the inter-hepatic lymph sinuses, where they become greatly elongated and tightly pack the organ. According to Leiper (1915) the ends of the second generation sporocysts are solid, but the walls of the tubules are delicate and transparent, so that they invariably rupture when attempts are made to tease them out of the host tissues. Upon maturity of the bifid cercariæ within the daughter sporocyst they escape through rupture of the distended integument of their mothers, and are discharged periodically from the mollusc in "puffs."

The Cercaria.—The cercaria (Fig. 26) of *Schistosoma hæmatobium* consists of an elongated oval body and a tail, which comprises a trunk and two furci. When the cercariæ escape naturally from their molluscan host (some six weeks or more after the miracidium first entered the snail) they are always mature. The integument of both body and tail is provided with minute spines. The tail is purely a larval structure, enabling the cercaria to swim about in a jerky nervous manner during its free existence. On penetration into the definitive host the caudal organ is left behind. Although the cercaria is frequently quiet in an unconfined environment its measurements are very difficult to determine accurately when under a microscopic cover-glass. Various authors have computed the length and breadth of relaxed specimens as follows: Length of body proper, 140 to 240 μ; of tail trunk, 175 to 250 μ; of furci, 60 to 100 μ; breadth of body, 57 to 100 μ; of tail trunk, 35 to 50 μ. The body of the cercaria is provided with an anterior blind sucker (*as*), measuring about 60 μ in cross-section by 64 μ in depth. The ventral sucker (*vs*), which is situated in the posterior fourth of the body is very much smaller. The oral opening is a small pore (*op*) which lies ventral to the anterior sucker. It leads into a capillary tube (the

esophagus) which ends in a slightly bilobed pocket in the mid-region of the body (the beginning of the furci). There is no pharyngeal sphincter. The excretory system is identical with that of the

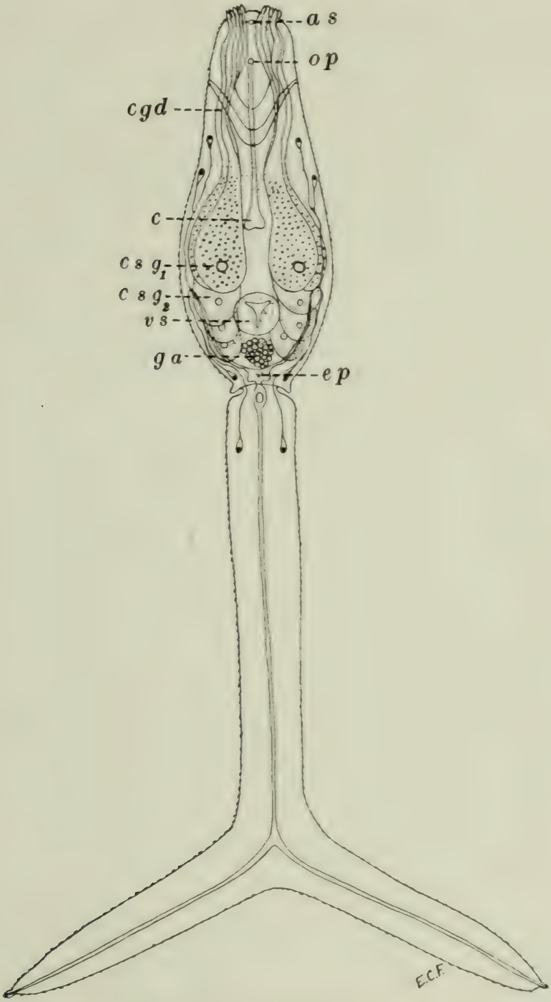


FIG. 26.—Cercaria of *Schistosoma hæmatobium*. *as*, anterior sucker; *c*, cecum; *cgd*, cephalic salivary gland ducts; *csg*1 and *csg*2, cephalic salivary glands; *ep*, excretory pore; *ga*, genital fundament; *op*, oral pore; *vs*, ventral sucker. × 340. (Original.)

cercariæ of *S. mansoni* and *S. japonicum*. There is a small spherical cluster of genital cells (*ga*) posterior to the ventral sucker. Nerve elements are present posterior to the anterior sucker. The most conspicuous structures in the body of the cercariæ are the cephalic

secretory glands (*csg*), with their swollen ducts (*cgd*), which open anteriad through the wall of the anterior sucker. Except for the type and number of these glands and for the somewhat larger size of the cercaria, this stage of *Schistosoma hæmatobium* is not distinguishable from the cercariæ of the other human blood flukes. In the case of the cercaria of *S. hæmatobium* (Fig. 26) these organs consist of three pairs of posteriorly situated unicellular glands, with homogeneous contents and a basophilic reaction, and two pairs of unicellular glands with granular contents and oxyphilic reaction, situated just in front of the former. These are in contrast to the four pairs of posteriorly disposed basophilic glands and two pairs of anteriorly disposed oxyphilic glands of *S. mansoni* (Fig. 38) and the five pairs of oxyphilic glands of *S. japonicum* (Fig. 50; see also diagnostic table, p. 153).

Infection of the Definitive Host.—The cercaria, on coming in contact with a mammal, penetrates the skin by digesting its way through the layers of tissue, enters the venous circulation either directly or by way of lymph tracts, passes through the lungs to the systemic circulation and develops to adulthood. The minimum period of incubation (*i. e.*, that from exposure of the skin to the infective cercaria until the worms are sexually mature in the portal blood), is not less than one month, since eggs first appear in the urine from one to two months or more following exposure.

Pathological and Clinical Aspects of Schistosomiasis Hæmatobia.—Schistosomiasis hæmatobia is commonly referred to in the literature as vesical schistosomiasis, urinary schistosomiasis, bilharziasis, bilharziosis, bilharzia infection, and endemic hematuria. These commonly employed names all refer to the condition produced by the presence of adult *Schistosoma hæmatobium* in the pelvic plexuses and by the eggs which are laid by the females and which work their way through the bladder wall and surrounding tissues. As a matter of fact, the first stage of the infection, affects entirely other organs and tissues than do the later stages, with characteristic symptoms of toxemia which appear to be similar in all three common types of human schistosomiasis, so that the term schistosomiasis hæmatobia is a more accurate designation than any of the more commonly accepted names.

The Incubation Period.—The first stage of the disease, namely, the *incubation period*, or that of invasion and maturation of the parasite, was studied by Lawton in Australian troops stationed in Egypt in 1916 and by Fairley both in human cases and in experimentally infected monkeys. In addition, there is the case of accidental auto-infection by Cawston, incurred while collecting snails along the banks of infested pools in the vincinity of Durban, Natal. The earliest symptom which has been noted is a tingling sensation of the skin upon coming out of "infected water" after swimming, or

an itching of the skin (Fig. 16) on the part of persons constantly wading in such water. Some hours later small petechiæ may at times be found over areas of skin exposed to the infection. These minute lesions, which are at the points where cercariæ have penetrated the skin and have reached the peripheral bloodvessels, entirely disappear in the course of a day or two. No further symptoms occur for a period of three weeks or sometimes as much as twelve weeks, when there is either a gradual or a sudden onset of toxic symptoms, the latter usually being associated with some unusual bodily exertion. These symptoms consist of anorexia, headache, malaise, and generalized pains in the back and extremities, with temperature in the late afternoon or evening, frequently accompanied by rigor and sweating. There is commonly an urticarial rash which is most pronounced on the limbs but gradually becomes generalized over the body. Blood examination at this time shows a leukocytosis, with a marked eosinophilia which frequently reaches 50 per cent or more. The abdomen often becomes distended, liver and spleen become enlarged and tender, while sharp pains may be felt in the pericardial region and respiration may become somewhat difficult. There is apparently no diarrhea or dysentery in typical uncomplicated cases of schistosomiasis hæmatobia. In areas where natives are constantly subject to reinfection, the uncomplicated symptoms of this period of the disease are difficult to recognize, particularly since urticaria is rarely seen.

The lesions produced during the period of migration of *Schistosoma hœmatobium* from the skin to the portal spaces, consisting of hemorrhages in lymph nodes and capillaries and the accumulation of white cells around the schistosomula lodged in the subcutaneous tissues, somatic musculature, intestinal wall, kidneys, diaphragm and heart, have not been studied in this infection as intensively as they have in schistosomiasis japonica (Faust and Meleney), but it seems reasonable to believe that they are similar. Nor have the lesions during the stage of maturation of the parasite been studied, except from the indirect evidence of the blood picture and of the generalized toxemia.

The Period of Egg Deposition and Extrusion.—Following the period of invasion and maturation of the parasite is that of *egg deposition and extrusion.* Although the worms are presumably mature and the females are supposedly capable of laying eggs from four to five weeks after exposure to infection, several months may elapse before the bladder becomes involved, and before the characteristic terminal-spined eggs appear in the urine. In Cawston's case eight and a half months intervened between the onset of toxic symptoms and the first appearance of eggs in the urine. During the latter part of this interval there are usually no special symptoms. The patient is first aware of the disease by the painless passage of

blood at the end of micturition. This may continue for years without subjective symptoms, during which time eggs are commonly evacuated in the urine. Sooner or later, however, a burning sensation is experienced at the time of and between the periods of micturition, and the desire to urinate more frequently becomes increasingly felt. In uncomplicated cases dull pains in the loins and suprapubic region and sharp colicky pains in the bladder may be experienced. Examination of the inner end of the urethra and the adjacent region of the bladder will show involvement of the mucous membranes and frequently the presence of papillomatous folds. Concretions of uric acid and oxalate crystals are not uncommon in the

FIG. 27.—Eggs of *Schistosoma hæmatobium* in the bladder wall. Greatly enlarged. (After Manson-Bahr, in Manson's Tropical Diseases, 1925.)

lumen of the bladder. Meanwhile eggs may have become infiltrated around the prostate or into its tissues, producing induration and causing tenderness of the prostatic region. Even the male generative organs and their tubules may become involved in the general infiltration.

The mechanism for deposition of the eggs of *S. hæmatobium* into the venules and extrusion into the wall of the bladder and the surrounding tissues has already been described (see pp. 107–108). Fairley has found that as many as twenty ova may be deposited in a single venule having a diameter much less than that of the egg, thus giving the "appearance of a string of miniature sausages." The blood current drives the spine into the wall of the venule. By means of this weapon, and due also to the histolytic substances elaborated by the enclosed larva and exuded through the egg shell, a way is

made into the perivenous tissues. At first the only changes in the bladder wall are the injection of the small bloodvessels of the mucosa and very minute vesicular or papular elevations of the membrane, which, on microscopic examination, are found to contain ova, surrounded by giant cells and leukocytes, including large numbers of eosinophils. At a somewhat later stage the trigonum vesicæ shows rounded patches of inflammatory thickening, which are superficially granular and full of gritty particles. On section the eggs are found to be abundantly distributed in the muscularis and submucosa and to a lesser extent in the mucosa itself. Some occlude the bloodvessels. (See Fig. 27.) Most of these eggs are viable but some are undergoing calcification. The inflammatory patches on the surface of the bladder may consist of sloughing tissue or phosphatic deposits around eggs, or both.

The Stage of Tissue Proliferation and Repair.—The third stage is *the stage of tissue proliferation and repair.* It is initiated soon after egg extrusion into the tissues and consists first of all of an increase in the pathological condition of the bladder, including hyperplasia of the wall, so that the symptoms gradually assume the condition of chronic cystitis, aggravated by secondary infection. In the bladder itself phosphatic deposits on the wall become more and more confluent so as to form the typical "sandy patches," the urine changes from acid to alkali in reaction, with an abundance of mucus, pus and blood cells. The calculi in the bladder, which at first consisted of oxalates or uric acid crystals around eggs or a sloughed portion of a papilloma or a blood clot, may now be increased by the deposition of phosphatic deposits, so that the stone becomes quite large. Meanwhile the urethra is more and more involved and may become entirely occluded, either from general hyperplasia or nodular swellings or from the attempted passage of purulent débris accumulated within the bladder. Likewise the lower portion of the ureters may become affected and occasionally involvement may even reach the pelvis of the kidney. Concurrently schistosomiasis of the penis may develop, resulting in induration of the sheath and an elephantoid appearance of the organ (Figs. 28 and 29) due to obstruction of the scrotal lymphatics. The invasion of pyogenic organisms is not uncommon at this stage, giving rise to perivesical and periurethral abscesses, which break through into the bladder, or produce fistulæ into the rectum, or may involve the entire scrotum and penis in multiple fistulæ. At times pus may ooze out of the scarred and contracted meatus as in gonorrhea. In the female there are similar changes in the vagina. The disease may even invade the uterus.

This stage is accompanied by extreme weakness, emaciation and intense pain in micturition. The intervals between periods of micturition become shorter and shorter and the amount of urine

passed at each period becomes smaller and smaller, finally consisting of little else than pus and blood, which dribbles out uncontrolled. With such profound involvement of the entire urinary tract the patient gradually wastes away, or his demise may be hastened by secondary septic involvement.

Fig. 28.—Schistosomiasis hæmatobia of the penis, with multiple fistulæ. (After Madden, Journal of Tropical Medicine and Hygiene.)

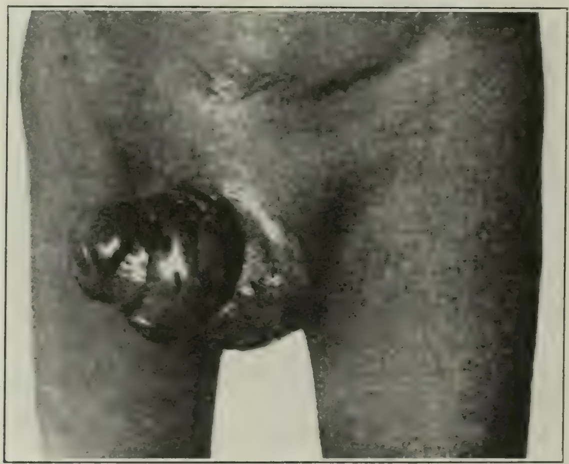


Fig. 29.—Schistosomiasis hæmatobia of the penis, with elephantoid appearance of the surrounding tissues. (From Byam and Archibald, Practice of Medicine in the Tropics.)

While the primary pathological changes in case of schistosomiasis hæmatobia involve the urino-genital system, other organs, particularly the liver, in which eggs are lodged and are sooner or later

extruded into the tissues, partake of the picture of hyperplasia followed by fibrosis and necrotic degeneration. These possibilities must be considered in estimating the damage done in any particular infection. (For the more severe involvement of the liver and spleen in schistosomiasis mansoni and schistosomiasis japonica see pp. 129 and 148–149 respectively).

Ferguson has shown that in a large number of cases of schistosomiasis hæmatobia in Egypt there are malignancies of the bladder, usually of the posterior wall (Fig. 30), although at times involving the entire organ.

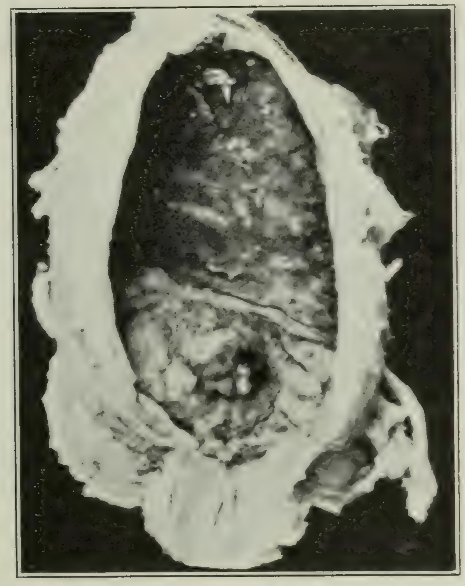


FIG. 30.—Schistosomiasis hæmatobia with malignant growth of the bladder. (After Ferguson, Journal of Pathology and Bacteriology.)

In spite of the fact that *Schistosoma hæmatobium* has a special predilection to invade the vesical veins, eggs are occasionally passed from the venules of the inferior mesenteric vessels directly into the wall of the rectum, and are evacuated in the feces.

Diagnosis and Treatment.—During the period of invasion and maturation of the parasite no positive diagnosis can be made, although the patient's history and the blood picture may be suggestive of schistosomiasis. Practically all native cases, however, are more advanced when they appear in the clinic. Cystoscopic and digital examination through the rectum will afford considerable assistance, while hematuria is an almost invariable accompaniment of the disease. The finding of *Schistosoma hæmatobium* ova in the

urine, especially in the last portion of urine voided, is the most definite diagnostic demonstration. Fairley's complement fixation reaction (p. 534) is helpful in early cases or in doubtful cases in which eggs cannot be recovered from the urine. The disease must be differentiated from renal calculus, from acute nephritis, from benign papillomata and malignant disease of the bladder, hemoglobinuria, oxaluria, and tuberculous lesions of the urinary tract.

Symptomatic treatment is not in itself of great benefit, since the long life of the parasite (twenty years or more) makes it likely that continuous extrusion of eggs into the region of the bladder will aggravate rather than simplify the condition. Tartar emetic is a

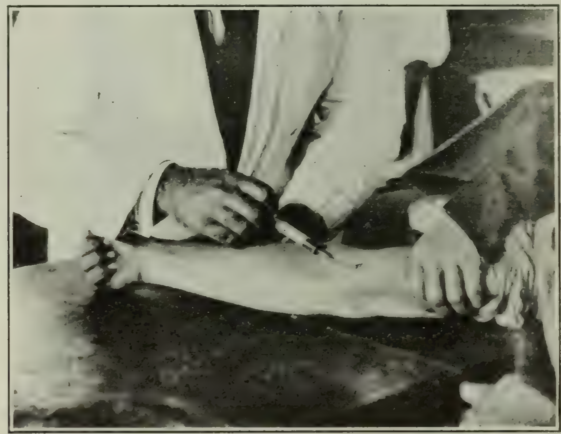


FIG. 31.—Method of injecting tartar emetic solution into the vein, in use in schistosomiasis clinics in Egypt. (After Khalil.)

specific schistosomaticide, and in cases in which the urinary tract has not been profoundly affected intravenous injection of the drug (Fig. 31) brings about rapid improvement, while a sufficient course of treatment effects a permanent cure. Sodium antimony tartrate is the drug of choice and may be given to the majority of cases as out-patients. In the extensive therapeutic campaign in and around Cairo following the introduction of tartar emetic the course of treatments with the drug (6 per cent solution) covering a period of four weeks has been as follows:

	Mgs. of sodium antimony tartrate.		
	First visit.	Second visit.	Third visit.
First week	60	90	120
Second week	120	120	120
Third week	120	120	120
Fourth week	120	120	120

For women and children the dosage is reduced, as it is also when dizziness and vomiting occurs. For small children and others in which it is impossible or unwise to do intravenous injection subcutaneous injection of emetine hydrochloride is preferable. Two cc. of a 3 per cent solution is given three times a week for a course of eight to ten injections. For children doses of 1 cc. are ordinarily sufficient. The usual aseptic precautions must be observed, and in the case of tartar emetic great care must be exercised not to allow even a drop of the solution to get outside of the vein. The effect of the drug may be determined both by observing the improved condition of the patient and by the gradual change in the appearance of the eggs in the urine, resulting finally in the passage of sterile ova and then by their total disappearance, following the death of the parent worms.

In advanced cases where the bladder and surrounding tissues have been profoundly affected antimony therapeusis can avail little. Surgical treatment is indicated in case of bladder calculi, neoplasms and fistulæ, while mercurochrome-220 may be helpful in clearing up pyogenic infections. In both curable and non-curable cases palliative and tonic treatment is often advisable.

Epidemiological and Prophylactic Considerations.—All authorities agree that infection with *Schistosoma hæmatobium* is incurred through contact with "infected water," and that the infective stage of the organism is the cercaria which has been liberated from the molluscan intermediate hosts of the fluke. In Egypt, where most consideration has been given to studying the epidemiology of the infection, every province of the country is known to be infected, the incidence of infection according to a survey quoted by Khalil varying from 68.4 to 91 per cent. Furthermore, the disease has been on the increase as the irrigation projects from the Nile have been extended into previously arid districts. The distribution of the snails is such as to cause the cercariæ to be present not only in the irrigation ditches in the fields but also in the larger canals passing through the villages. Unfiltered city water, which comes from infected foci, is likewise highly dangerous. Thus, not only the farm laborers in the fields but also the women washing in the canals and the children bathing in the larger bodies of water are constantly exposed to the infection. Moreover, it is not unlikely that cercariæ taken into the mouth with raw drinking water can enter the oral mucosa and cause infection. The vicious cycle is increased the more by the observance of certain religious practices. The Mohammedan religion prescribes that the urethral and anal openings be washed with water after urination or defecation. The villagers therefore seek the bank of the nearest water course into which they urinate or defecate in order to wash afterward. Thus a rite originally intended to foster cleanliness has been turned into a most

dangerous practice. However, according to Khalil, the Mohammedan religion prohibits the pollution of water courses with human excreta, unless the volume of water is large and the flow is considerable, which is not true of most of the irrigation canals. In South Africa Cawston has found that the infected portion of the water

A

B

Fig. 32.—Schistosomiasis endemic area in Natal, South Africa. *A*, large infected pool at Sydenham, *B*, boys wading in infected pool. (Photographs by Dr. F. G. Cawston.)

courses lies in the pools and along the river banks below the discharge of sewage from towns and cities, where school children are particularly apt to wade about and bathe (Fig. 32, compare with Fig. 16, p. 98). In Sierra Leone, where Blacklock has studied the problem, infected specimens of Bulinus have been found in pools below latrines, where the villagers wash and bathe. Thus the infected areas may be roughly divided into two groups, namely, (1) those in which all of the fresh water is more or less contaminated by infected excreta and (2) those in which infection is localized in or below community latrines or where sewage enters a water course. All of the data show that the snails involved are sewage-feeders, although the species serving as hosts in South Africa (*Physopsis africana, Bulinus tropicus*) and in Sierra Leone (*Physopsis globosa*) are possibly more adapted to polluted water than are the Egyptian species.

With the discovery of tartar emetic as a specific schistosomaticide attempts have been made in and around Cairo and Khartoum to decrease the amount of the infection in these areas by mass therapy. Thousands of cases have been successfully treated, but the constant exposure of individuals to subsequent infection and the apparent lack of immunity to subsequent infections on the part of previously infected individuals make this procedure hopeless as a single public health measure. All investigators agree that much good should result from educational propaganda concerning the disposal of excreta, while Khalil, following the recommendations of Leiper, has demonstrated that much may be expected in Egypt in concerted attempts to exterminate the snail hosts, utilizing the combined effects of desiccation during the intervals when the canal sluiceways are closed, and treating dry canals with copper sulphate.

CHAPTER XII.

THE HUMAN BLOOD FLUKES (CONTINUED).

SCHISTOSOMA MANSONI, S. JAPONICUM, S. BOVIS, S. SPINDALE AND S. INCOGNITUM, THE CAUSATIVE ORGANISMS OF INTESTINAL SCHISTOSOMIASIS.

1. **Schistosoma mansoni** Sambon, 1907.

Synonyms.—*Distoma hæmatobium* Bilharz, 1852, *pro parte*, Bilharz, Looss, *et al.*, *Schistosomum americanum* da Silva, 1909.

Historical.—In his original researches on human blood flukes in Egypt Bilharz noted that certain female worms contained lateral-spined eggs. Sonsino and Manson both believed such worms to be separate and distinct species from those producing terminal-spined eggs. The observations of Castellani in Uganda (1902) and of Manson in the West Indies (1903) served to show a somewhat different geographical distribution of the worms with the two types of ova. In 1907 Sambon proposed the species name *mansoni* for the worms producing the lateral-spined ova, basing his proposal not only on the different size and shape of the eggs from those of the typical *S. hæmatobium*, and the different geographical distribution of the two types, but also on the grounds that the female worms of the two types were different, in that the one only produced lateral-spined eggs, while the other only produced terminal-spined eggs, and, furthermore, on the fact that lateral-spined eggs were only recovered from the feces, while terminal-spined eggs appeared almost exclusively in the urine. Da Silva (1909) first described the greater number of testes in the male *S. mansoni*. The work of Flu (1911) in Surinam served to substantiate Sambon's view and showed that *S. mansoni* lived in the mesenteric veins while *S. hæmatobium* resided for the most part in the pelvic plexuses. These views were bitterly opposed by Looss, who believed the lateral-spined eggs to be unfertilized varieties of terminal-spined ones. However, in 1915 Leiper demonstrated experimentally that the two species were distinct and that the one (*S. mansoni*) was the causative agent of intestinal schistosomiasis while the other (*S. hæmatobium*) was responsible for vesical schistosomiasis. The data of Chalmers and Pekkola (1917), Lutz (1917) and Iturbe (1917) were all in accord with Leiper's findings.

Geographical Distribution of Schistosoma mansoni.—Schistosomiasis mansoni (Fig. 19, p. 100) occurs in the lower Nile delta,

where it is particularly common in the male fellaheen population. It also appears to be widespread in the Upper Sudan. In East Africa it is found along the coast from Zanzibar to the Zambesi River and inland through Northern Rhodesia and Tanganyika to the Belgian Congo. It is frequently recorded from Madagascar. Autochthonous cases are known from Natal and the Transvaal. On the West Coast the infection is found in Senegal, French Guinea and inland to the Lake Chad district. It is common through the Congo basin. However, careful investigation in Sierra Leone has failed to demonstrate its presence in that region. In the Americas

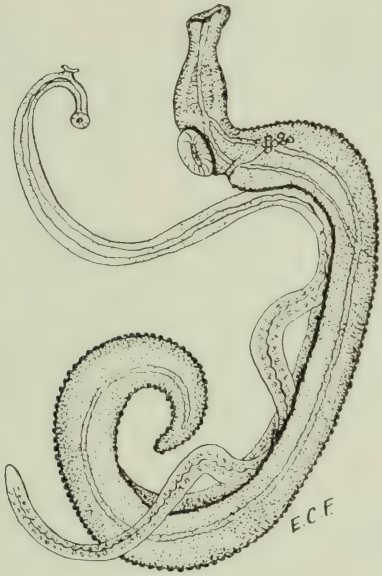


FIG. 33.—Adult male and female *Schistosoma mansoni* in copula. × 12. (Original)

intestinal schistosomiasis is common in Brazil, Venezuela and the Guianas. It has been reported from Peru, Panama and Costa Rica. It is known to be present in the Lesser Antilles, especially in Antigua, Guadeloupe, Martinique and Barbadoes. It also occurs in Porto Rico. Patients with *S. mansoni* eggs in their stools have been reported from North America but no autochthonous case is yet known. In Africa schistosomiasis mansoni is frequently coexistent with schistosomiasis hæmatobia, from which it must be differentiated; in the New World it is the only human blood fluke infection.

Structure and Life Cycle of Schistosoma mansoni.—In general the adult male and female of *Schistosoma mansoni* (Fig. 33) resemble those of *S. hæmatobium.* The female is somewhat smaller than that of *S. hæmatobium,* measuring from 12 to 16 mm. in length. The

ovary lies in the anterior half of the body just in front of the junction of the intestinal ceca. The vitellaria are more numerous than those in *S. hæmatobium,* occupying the posterior three-fifths of the body. On the other hand the uterus is very short and contains one or at most only a very few lateral-spined eggs. The male is also slightly shorter than that of *S. hæmatobium,* having a length of 10 to 12 mm. The integumentary tuberculations of the male are more prominent than those of *S. hæmatobium* males. The testes number eight or nine (Fig. 34) and an equal number of efferent ducts lead into the vas deferens which swells to form the seminal vesicle. The latter organ opens through the genital pore which is situated just posterior to the ventral sucker.

Adult worms of this species usually reside in the mesenteric veins. At the time of ovoposition the females wander ahead of the males into the small venules supplying the intestinal wall, and after forcing their way into vessels with a normal diameter considerably less than their own, deposit their eggs, retreat a bit, then lay another egg and so on, until the venule is distended to the bursting point. The laterally situated spine catches in the intima of the vessel, while the obstruction of the vein further distad by the female worm and the secretion of histolytic juices into the immediate vicinity by the larvæ within the eggs weaken the wall of the vessel, resulting eventually in its rupture, so that the eggs are extruded into the adjacent submucosa and mucosa of the intestinal wall, which soon gives way, allowing the eggs to be set free into the intestinal lumen, together with a small effluent of blood.

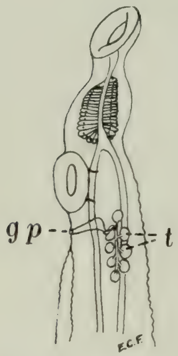


FIG. 34.—Anterior end of male *Schistosoma mansoni,* showing reproductive organs. (Original.)

The egg as it is recovered from the feces (Fig. 35) is fully mature. It is oval at both ends and is provided with a sharp lateral-spine. It averages from 140 to 165 μ in length by 60 to 70 μ in transverse diameter. The enclosed miracidium (Fig. 36) is somewhat larger than that of *S. hæmatobium* (Fig. 24). The ciliated epithelium and the internal organization is very much like that of the miracidia of *S. hæmatobium* and *S. japonicum,* although the details of its structure have not been studied as carefully as in the other two schistosome larvæ. The most conspicuous difference is the relatively larger size of the anterior pair of secretory glands (*sg*) and of the primitive gut (*pg*), which structures considerably overlap the lateral secretory glands.

Upon dilution in canal or pond water of the feces containing *S. mansoni* eggs, hatching occurs, the miracidium escaping through a

break in the shell. The free-swimming existence of the miracidium is similar to that of *S. hæmatobium*. On coming in contact with the appropriate molluscan host, the larva attacks and penetrates the soft tissues of the snail. In Egypt and the Sudan the commonly infected snail is *Planorbis boissyi*. In Natal *Planorbis pfeifferi* and *Physopsis africana* appear to be the usual molluscan hosts. In Nyasaland *Planorbis sudanicus* is said to be involved. In the Western World *Planorbis olivaceus* and *P. centrimetralis* in Brazil and *P. guadeloupensis* in Venezuela, Porto Rico and the Antilles have been incriminated as the principal hosts. (See Fig. 37.)

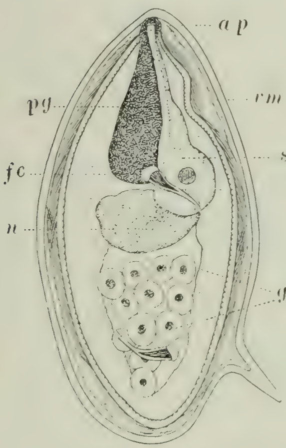


FIG. 35.—Mature egg of *Schistosoma mansoni*. × 370. (After Cort, Univ. of California Publications in Zoölogy.)

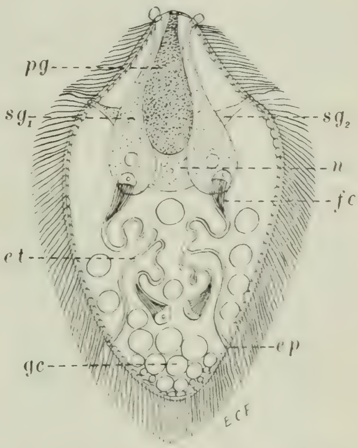


FIG. 36.—Miracidium of *Schistosoma mansoni*. × 400. Lettering as in Fig. 24. (Adapted from Cort, Univ. of California Publications in Zoölogy.)

The development of *S. mansoni* within the mollusc parallels that of *S. hæmatobium*, involving two generations of sporocysts and the eventual formation of cercariæ within the brood cavity of the second generation sporocysts. The mature cercariæ which emerge from the inter-hepatic lymph spaces of the snail (Fig. 38) are superficially very much like those of *S. hæmatobium* (Fig. 26). They are somewhat smaller, having body measurements of 140 to 190 μ in length by 50 to 75 μ in breadth; a tail trunk 200 to 260 μ long by 25 to 40 μ in cross-section and furci 50 to 75 μ long. The main diagnostic difference lies in the cephalic secretory glands, of which the cercariæ of *S. mansoni* have two anterior pairs with granular contents and oxyphilic reaction and four posterior pairs with mucoid contents and basophilic reaction. The method by which cercariæ of this species attack and invade the mammalian

host and migrate through its body to the portal system does not vary from that of *S. hœmatobium.*

Pathological and Clinical Aspects of Schistosomiasis Mansoni.—The disease produced by the presence of *Schistosoma mansoni* in the portal vessels is commonly referred to as intestinal schistosomiasis. The clinical picture and the pathological anatomy are in most respects comparable to those of schistosomiasis japonica and are usually distinct from those of schistosomiasis hæmatobia except during the period of migration and maturation of the worms, when the symptoms of toxemia appear which are common to all three infections, consisting of remittent fever, urticaria, abdominal pain, anorexia, rigors and labored breathing. The blood picture shows a leukocytosis and profound eosinophilia (40 per cent or more). During the end of this period of incubation, namely, from the

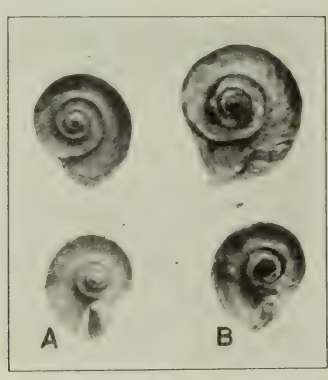


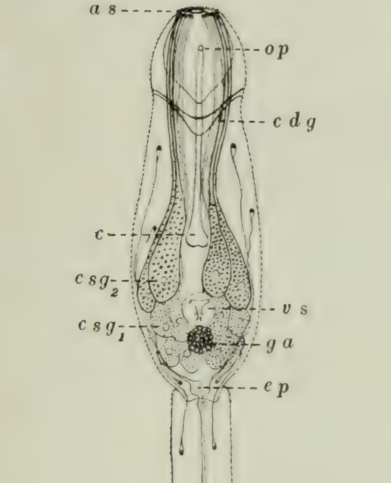
FIG. 37.—Molluscan hosts of *Schistosoma mansoni*. *A*, *Planorbis boissyi* from Egypt. *B*, *P. guadeloupensis* from Venezuela. Natural size. (Original photographs.)

third to the fifth week after exposure to infection, diarrheic and dysenteric complications are frequent and shortly after the extrusion of eggs into the intestinal wall eggs appear in the stool. They are not equally distributed throughout the fecal mass but are most commonly found in the flecks of bloody mucus which are voided after the fecal matter is passed.

The second period, which begins with the extrusion of eggs into the intestinal lumen, is accompanied by irregular dysentery, the so-called *schistosomiasis dysentery,* and a gradual involvement of the liver and spleen. The dysenteric symptoms consist of abdominal pains and the frequent passage of motions composed of a small amount of fecal matter and considerable blood-stained mucus, the latter usually containing the lateral-spined ova. This picture is commonly complicated by a prolapse of the rectum. The liver is frequently enlarged and tender and the spleen may become passively engorged. In uncomplicated cases the urine is negative for albumen

and sugar and only occasionally contains the lateral-spined ova. (In 4799 cases of schistosomiasis in Cairo in 1923, in which eggs were detected in the urine, three cases with *Schistosoma mansoni* ova were found.)

The condition which has just been described is caused by the escape of eggs from the portal vessels, including both the mesenteric



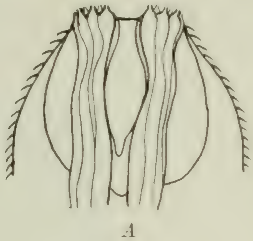


FIG. 38.—Cercaria of *Schistosoma mansoni* × 340; *A*, anterior end of cercaria, enlarged, to show openings of cephalic gland ducts. Lettering as in Fig. 26. (Original.)

vein and the intra-hepatic portion of the portal system. The presence of these eggs in the tissues of the gut provokes a dense cellular infiltration, leading to a thickening of the bowel wall and an excess of mucus production. These lesions gradually enlarge, so that on the mucosal surface localized areas of hyperemic tissues develop into abscesses, which break through the mucosa to the surface, causing minute hemorrhages with the discharge of bloody mucus, pus and eggs. These minute ulcers frequently become quite extensive, particularly if secondary infection develops. On the peritoneal surface the inflammatory process may extend to the peritoneum, resulting in hyperemia of the layer and at times in hemorrhages, with fibrous adhesions. In early cases the small intestine is most commonly involved but as the disease progresses the cecum, colon and rectum partake of these changes. The eggs which are carried to the liver and escape into the tissue produce

minute localized lesions, consisting microscopically of abscesses and pseudotubercles produced around the eggs. Hematin pigment has also been found by Fairley in various phagocytic cells. The eggs may escape into the lungs, stomach, pancreas, spleen, kidneys, lymph glands, suprarenals and myocardium, where they set up similar reactions.

The third period of the infection, that of tissue proliferation and repair, is marked by the production of papillomata of various sizes and shapes along the entire intestinal tract (Fig. 39) from the ileum

Fig. 39.—Colon in case of advanced schistosomiasis mansoni, with papillomata at left, healthy tissue at right. (After Richards, Journal of Tropical Medicine and Hygiene.)

to the anus, thickly distributed or sparsely scattered. The dysentery usually subsides somewhat, but at times there are frequent stoolings, with tenesmus. Likewise fibrous constrictions may appear along the length of the intestine, particularly in regions where the wall has become thickened and packed by the schistosomiasis abscesses. In late cases the sphincter ani becomes patulous, allowing masses of pedunculated tissue to protrude (Fig. 40). Fistulous tracts may extend into the ischio-rectal fossa, the perineum, the buttocks or even into the bladder area. Ulceration and epitheliomatous growths in this region are dangerous complications. Splenomegaly with ascites (Fig. 41) is a concomitant symptom in a certain percentage of cases and is by no means uncommon in children.

The pathological picture of the intestine during this period is that of irregular thickening, with a massive increase in fibrous

tissue. More serious is the hepatic cirrhosis, which Symmers has referred to as a "clay pipe-stem cirrhosis," on account of the thickening of the larger veins of the liver, due to toxic secretions of the worms and ova and to passive congestion. With this is associated the production of scar-tissue in all inflammatory foci.

Diagnosis and Treatment.—During the period of invasion and maturation diagnosis is the same as that for schistosomiasis hæmatobia; during the period of dysentery specific diagnosis is based on the finding of lateral-spined eggs in the stool. Special stress should be placed on the examination of flecks of mucus in the stool

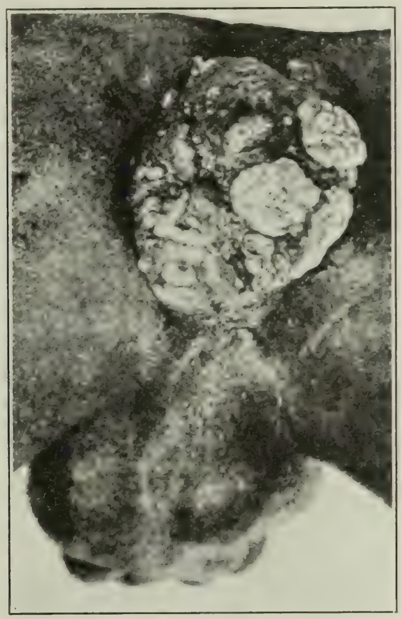


FIG. 40.—Schistosomiasis mansoni lesions of anus and surrounding tissues. (After Madden, Journal of Tropical Medicine and Hygiene.)

which are most likely to contain ova. In the third stage of the disease eggs are less frequently evacuated and diagnosis is more complicated. This stage should be differentiated from malignancies of the intestinal tract and from other varieties of liver cirrhosis and splenomegalies. The presence of eosinophilia and positive precipitin or complement-fixation tests in conjunction with the clinical picture may be considered as highly suggestive of schistosomiasis of the intestine. Tartar emetic is a specific therapeutic in cases of *Schistosoma mansoni* as it is in *S. hæmatobium* infection. The dosage and method of administration are essentially the same, but greater care should be exercised as regards the reaction of the patient to the

drug because of the greater damage to the liver caused by the disease. Papillomata of the rectum frequently require surgical treatment. Cases with advanced hepatic cirrhosis are rarely benefited by administration of antimony.

Epidemiological and Prophylactic Considerations.—The only serious study of the public health aspects of *Schistosoma mansoni* infection is that which has been made in Egypt, concurrently with *S. hæmatobium* infection. The molluscan host commonly lives in quiet channels or irrigation ditches and for this reason the field laborers are the only class usually affected. At times, however, where the village water supply becomes involved epidemics may break out. The same measures which apply to the prevention of *S. hæmatobium* infection are applicable to schistosomiasis mansoni. The fact that the West African green monkey (*Cercopithecus sabæus*) is a reservoir of this infection in Africa and the Lesser Antilles (St. Kitts) makes the problem of eradicating this organism a difficult task.

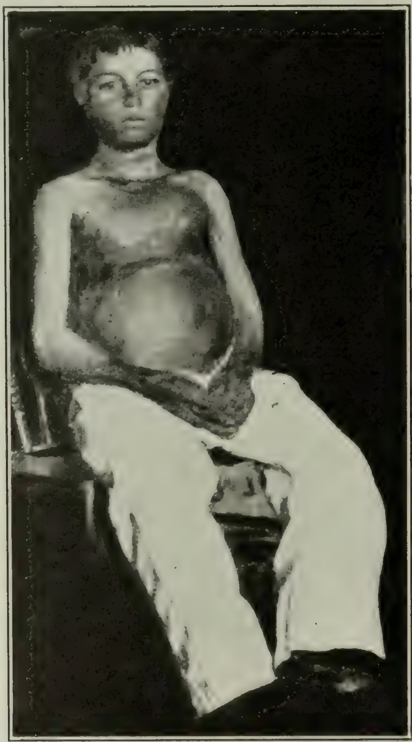


Fig. 41.—Schistosomiasis mansoni splenomegaly. (After S. B. Jones, Journal of Tropical Medicine and Hygiene.)

2. **Schistosoma japonicum** Katsurada, 1904.

Synonym.—*Schistosoma cattoi* R. Blanchard, 1905.

Historical.—The earliest record of the disease produced by *Schistosoma japonicum*, was that of Fujii in 1847. Baelz (1883) made an epidemiological survey of the schistosomiasis endemic area near Okayama and described the symptoms of the disease, but attributed them to *Clonorchis* infection. Yamagiwa (1890), Kurimoto (1893) and Fujinami (1904) all found the eggs of the then undescribed parasite in various organs of individuals who had died of the disease and recognized their etiological rôle in the disease. Kasai (1903) first found the eggs in the feces. Fujinami (May, 1904) obtained a single female worm in the portal vein of a man, which was probably the first adult specimen found. Katsurada (April, 1904) investigated the infection in the Yamanashi endemic area and from a study of the symptoms in 5 patients, from whom he had obtained the eggs, suggested "that the disease was caused by these eggs and the mother worms, and that the latter were apparently present in the portal system." Unable to secure human autopsies he examined dogs and cats and from the latter obtained specimens of the adult worms, proposing for them (December, 1904) the species name, *Schistosomum japonicum*. Katsurada's paper included an accurate description of the eggs and the parent worms, together with the pathological picture of the disease. One month later (January, 1905) Catto described a worm from the mesenteric vessels of a Chinese who had died in Singapore. Blanchard christened this form *S. cattoi*, but it was soon found to be identical with *S. japonicum*. The same year Logan found the eggs of this fluke in Chinese patients in Hunan Province, China. Following this many Japanese medical men studied the infection, investigating the morphology of the parasite, its effect on the host and the distribution of the disease in Japan. By 1909 Fujinami had discovered that cattle and horses were natural hosts, as well as man, dogs and cats, and by critical experiments proved conclusively that the skin was the usual portal of entry of the infective stage for man. Miyagawa (1912–1913) studied the route of migration through the body, finding that the organism utilized the venous circulation *en route* to the lungs, thence *via* the systemic vessels to the mesenteric system, and finally through the mesenteric capillaries into the portal blood. Meanwhile Miyairi and Suzuki (1913–1914), working in the Kyushu endemic area, were making progress in the solution of the phase of the life cycle outside of the mammalian host. They first showed that the fork-tailed cercariæ, which had developed in small amphibious snails (*Katayama nosophora*), were the infective stage for mammals and further observed the hatching and penetration of *Schistosoma japonicum* miracidia into this species of snail and the development of two generations of sporocysts and of the

cercarial stage within this mollusc. Contemporaneously, but independently, Miyagawa verified the necessity of a mollusc as an intermediate host of the infection. In 1915 Leiper and Atkinson confirmed this work.

Various physicians in China, including Logan, Taylor, Peake, Houghton and Vickers, studied the symptomatology, pathology and distribution of schistosomiasis japonica in China (1905–1922); later Faust and Meleney (1923–1924) investigated the extent of the infection in China, showing that the disease was widespread in the Yangtze drainage and was present coastwise from Shanghai to Hongkong. These later workers found *Oncomelania hupensis* to be the molluscan host in the Yangtze Valley and *Katayama nosophora* along the southeast coast.

Geographical Distribution of Schistosoma Japonicum.—Schistosomiasis japonica is confined to the Far East and its distribution is coextensive with that of the small amphibious snails of the genus Katayama and the closely related genus Oncomelania. The regions of infection lie in Japan, China, Formosa and the Philippines (Fig. 19, p. 100). In Japan the disease is confined to five small foci, separate from one another, lying in widened valleys of coastal rivers. Four of these endemic areas are on the main island, one northeast of Tokyo, two near Mt. Fuji and one near Okayama; the other is in the northern part of Kyushu. Altogether these districts amount to only a few hundred square miles, and involve less than 100,000 people. In Formosa an infected area is situated at Shinchiku near the center of the island. As far as is known man is not infected in this district, the disease being confined to other mammals. In the Philippines, according to Mendoza-Guazon (1922), the disease is confined to the islands of Samar and Leyte. In China an enormous extent of territory is embraced in the schistosomiasis districts. These include a very large portion of the entire Yangtze Valley, stretches along the sea coast from the Yangtze delta to Hongkong, the North River district above Canton, and a newly described focus in the Upper Mekong basin in Yünnan. By far the greatest part of this territory is that in the Yangtze River basin from Szechuan Province to the sea, where practically all of the backwaters of this mighty stream, including lakes, ponds, small streams, canals and irrigation ditches, harbor the appropriate snail. All of this area is not equally heavily infected. The regions most severely endemic are those adjacent to the shores of the three lakes, Taihu, Poyang and Tungting, lying to the south of the Yangtze, as well as the districts immediately adjoining the Yangtze. The main courses of the larger tributaries and of the Yangtze River itself are not *per se* a source of danger. Altogether thousands of square miles are involved in these endemic foci, with a population of 100,000,000 people, of whom some 10 per cent are estimated to be suffering from the disease.

Structure and Life Cycle of Schistosoma Japonicum.—The adult worms of this species were carefully described by Katsurada (1904) in his original investigation of the species. The male is the larger, more robust and the female the more slender and longer (Fig. 42). In typical infections the males and females are about equal in number and the females are usually situated in the gynecophoral canal of the male. Both males and females lack the tuberculated integument found in *S. hæmatobium* and *S. mansoni*. The suckers lie close together at the anterior end. The ventral sucker in both sexes is like a shallow cup on a short broad base. The esophagus is

FIG. 42.—Adult male and female of *Schistosoma japonicum* in copula. (After Looss in Hegner and Cort.)

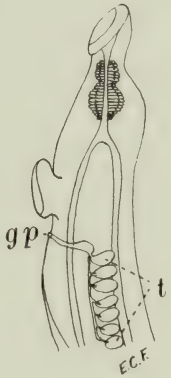


FIG. 43.—Anterior end of male *Schistosoma japonicum*, showing reproductive organs. (Original.)

surrounded by two contiguous clusters of glands (Fig. 43). The intestine bifurcates just in front of the ventral sucker, the ceca continuing posteriad to the last fourth or fifth of the body before reuniting.

The males measure from 12 to 20 mm. in length by 0.50 to 0.55 mm. in greatest diameter. Their integument is smooth except for a spinous covering of the suckers and of the gynecophoral canal. The testes are seven in number and lie side by side in a single column (Fig. 43). Each is provided with a short vas efferens which joins its fellows to form a common vas deferens, the latter enlarging into a seminal vesicle before opening to the exterior through the genital pore.

The female attains a length of 26 mm. and has an average diameter of about 0.3 mm. The integument is entirely smooth except for the suckers which are provided with minute spines. The ovary is situated somewhat behind the middle of the body in front of the union of the intestinal ceca. Posterior to the ovary are the vitelline glands which occupy most of the posterior fourth of the body. Emerging from the posterior end of the ovary is an oviduct, which bends abruptly forward and, running parallel to the vitelline duct, proceeds to the oötype. There is a seminal receptacle lying coiled to one side of the posterior end of the ovary, which opens into the oviduct near the origin of this duct. It seems possible, therefore, that in this species fertilization may take place before the naked egg cells reach the oötype. The oötype lies just in front of the midplane of the body. It is surrounded by shell glands which open into its lumen and is provided anteriorly with a sphincter which separates it from the uterus. The uterine tube is long, extending from the oötype to the genital pore immediately behind the ventral sucker. It may contain 50 or more eggs. The eggs in the proximal end are almost hyaline, while those near the genital pore are a pale yellow. The more mature uterine eggs are biconvex and regularly oval, except for a shallow depression on one side near one end, from which there extends a short recurved hook or abbreviated spine. The eggs which are ready for laying are still immature; they measure 67 by 50 μ.

When the female worms are ready to lay their eggs they extend the anterior part of their bodies considerably in front of the males into the smaller venules of the submucosa (see Fig. 52), or even into the mucosa (Faust and Meleney, 1924) but they apparently do not leave the gynecophoral canal of the males in the manner described by Fairley for *S. hæmatobium* and *S. mansoni* females at the time of oviposition. Here large numbers of eggs are deposited into the capillaries of the mucosa or submucosa, which become enlarged and congested. The eggs are thus deposited very close to the lumen of the intestine, where, by the slightest pressure or digestion of the intestinal epithelium, they are discharged into the lumen of the gut. The first eggs which are laid by the female worms pass through into the intestinal lumen almost immediately after deposition and are consequently still immature. As egg-laying proceeds and the intestinal wall becomes more and more thickened, the periods between deposition and extrusion become longer and longer, so that all stages of maturity of the eggs may be found in the tissues while in chronic cases calcified and otherwise devitalized eggs may accumulate. As the route into the lumen of the gut becomes more and more obstructed eggs are more commonly swept along in the blood stream into the liver.

The eggs extruded into the intestinal lumen (Fig. 44) are voided

with the feces. They measure from 70 to 100 μ in length by 50 to 65 μ in breadth. Defecation in endemic areas may occasionally be promiscuous but the stool is more frequently saved for manurial purposes. Night-soil is usually conserved in a liquid state in reservoirs which are situated on the banks of terminal or irrigation canals, where ample opportunity is afforded for the eggs to reach the water, thus providing conditions favorable for hatching. The shell membrane splits along the line of least resistance, allowing the miracidium (Fig. 45) to escape. On emerging from the shell on the sub-

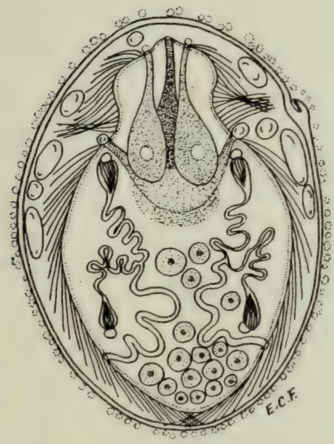


FIG. 44.—Mature egg of *Schistosoma japonicum*. The blood cells adherent to the shell are characteristic. × 600. (Original.)

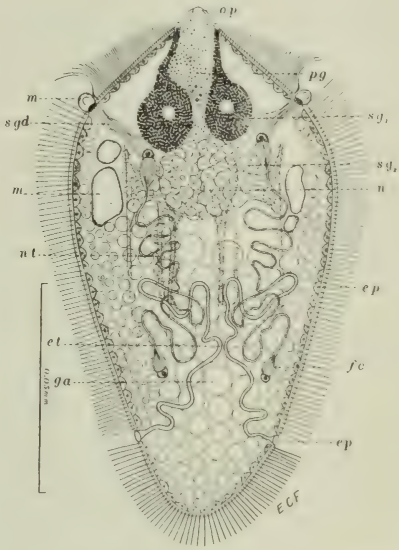


FIG. 45.—Miracidium of *Schistosoma japonicum*. × 550. Lettering as in Fig. 24. (After Faust and Meleney, Am. Jour. of Hygiene.)

stratum the larva begins to swim energetically in the water, the forward movement causing it to elongate somewhat. Like the miracidia of *S. hæmatobium* and *S. mansoni* it is provided with a ciliated epithelium, which is interrupted only at the very anterior end, at the openings of the lateral secretory gland ducts and at the openings of the two excretory ducts. Internally the miracidium of *S. japonicum* is provided at its head end with a primitive gut (*pg*), a pair of secretory glands (sg_1), packed with granular oxyphilic material and opening to the sides of the gut, and paired clusters of minute secretory glands (sg_2) of a basophilic reaction lying immediately posterior to the gut and having capillary ducts (*sgd*) opening through minute pores at the anterior-lateral margins. A central neural mass (*n*), with longitudinal extensions, is situated underneath the

basophilic secretory glands. There are two pairs of flame-cells (*fc*) with ducts (*et*) uniting on either side into a single deferent duct to open through pores on the postero-lateral margins (*ep*). Germ balls are proliferated from the posteriorly disposed germinal epithelium into the lumen of the miracidium, which serves as a brood cavity.

After swimming about for a short time in the deeper strata of water the miracidia of *S. japonicum* rise to within 2 or 3 cm. of the surface where they continue to swim about for twenty-four to thirty-two hours. It is in this top stratum that the appropriate snail is most likely to be found, particularly at the time when the water begins to rise to the level of those snails which are attached to grass and weeds on the banks of canals and irrigation ditches (Fig. 46). The molluscan intermediate hosts of the infection in

FIG. 46.—Habitat of *Katayama nosophora*, the molluscan host of *Schistosoma japonicum* in Japan. (Original photograph.)

Japan and along the coast of China from Shanghai to Canton, where the water comes from coastal mountain streams, is *Katayama nosophora* Robson (Fig. 47 *A*); throughout the Yangtze Valley, where the water is more loaded with salts and débris, the host is *Oncomelania hupensis* Gredler (Fig. 47 *B*); in Formosa it is *Katayama formosana* (Pilsbry and Hirasé). No search has yet been made for the mollusc involved in the Philippines, but it will most likely be found to be a species closely related to those of the Sino-Japanese areas.

On coming in contact with the appropriate snail the miracidium of *S. japonicum* attacks and penetrates the soft parts of the mollusc.

It may either enter the gill filaments and soon reach the blood stream from whence it is carried to the lymph channels, or it may invade the soft mesenchymatous tissues of the head or foot. In the latter event it digests the host tissue to form an artificial lymph channel, which soon extends to the true peri-intestinal lymph spaces. Meanwhile the ciliated epithelium is sloughed off, and the miracidium is transformed into a sporocyst, which migrates toward the inter-

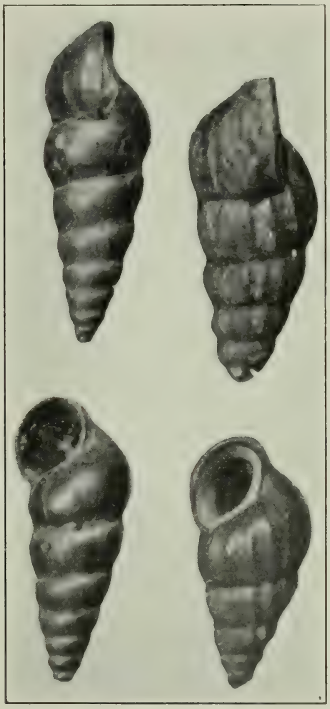


FIG. 47.—Molluscan hosts of *Schistosoma japonicum*. *A*, *Katayama nosophora*, *B*, *Oncomelania hupensis*. × 5. (After Faust and Meleney, Am. Jour. of Hygiene.)

hepatic lymph spaces, where second generation sporocysts (Fig. 48) develop within the parent sporocysts, erupt into the free lymph spaces surrounding the liver lobes, and, in turn, produce internally the fork-tailed cercariæ. These later on maturing are crowded within the thin-walled second generation sporocysts which pack the inter-hepatic lymph spaces (Fig. 49). On reaching complete maturity the cercariæ work their way out of the second generation sporocysts and are ready to emerge from the snail. This occurs only in case the snails are in the water. Thus snails which have

bored into the earth during the period of hibernation or those attached to grass above the water line, or those in cracks of dry earth, may be heavily infected but are not freed of their parasitic progeny until they fall into water or the water level rises to meet them, whereupon swarms of cercariæ erupt from the host tissues and rise to the surface of the water, where they may attach themselves by their ventral suckers or again sink to the bottom of the water. It is this brood of cercariæ lying just under the surface film in quiet shallow water which is probably responsible for the greater part of the infection incurred by persons wading in the infected water.

The free-swimming larva (Fig. 50) is a characteristic schistosome cercaria, with a forked tail and with the entire integument provided with minute spines. The body proper measures 100 to 160 μ in

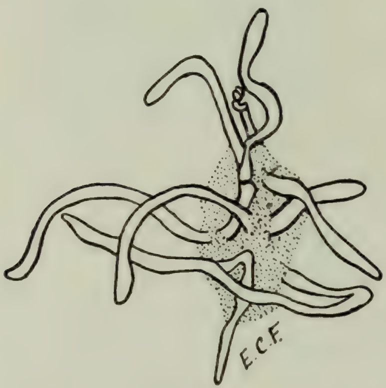


FIG. 48.—Second generation sporocysts of *Schistosoma japonicum* from *Oncomelania hupensis*, Central China. Greatly enlarged, (Original.)

length by 40 to 66 μ in transverse diameter. The tail trunk averages from 140 to 160 μ in length by 20 to 35 μ in cross section, and the furci from 50 to 75 μ in length. The anterior sucker (*as*) lies in front of the oral aperture (*op*). On its dorsal side there is a head gland (*hg*) opening into its blind inner aspect. A capillary esophageal tube leads into an enlarged bilobed cecum (*c*), which ends blindly near the middle of the body. The ventral sucker (*vs*) is situated in the posterior fourth of the body. It is small but very muscular. Just behind it there is a clump of genital cells (*ga*). The excretory system is identical with that of the other human schistosome cercariæ, consisting of two pairs of flame-cells on either side of the mid-line, the posteriormost cell residing in the proximal part of the tail. The collecting tubules enter the bladder from its anteriolateral aspects. The bladder has a minute dorsally situated excretory pore. A collecting tubule also extends from the posterior face

of the bladder into the tail, bifurcating as it reaches the caudal furci and opening at the end of each furcus through a minute pore.

On coming in contact with the exposed skin of a mammal, the cercaria attaches itself and attempts to penetrate the skin. This process is materially aided if the water-film containing the cercariæ on the surface of the skin begins to dry. All mammals which frequent "infected water" in infected areas appear to be susceptible to infection. Before attempting invasion or during the process the tail is discarded. After a period of twenty to twenty-four hours the cercariæ have digested their way through the skin, utilizing the histolytic ferments elaborated in the cephalic secretory ducts

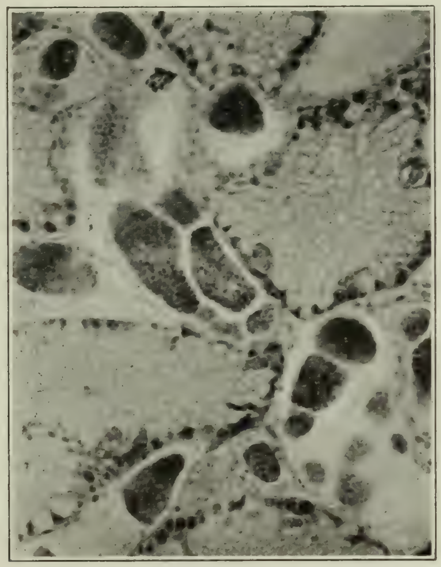


FIG. 49.—Cercariæ of *Schistosoma japonicum* maturing within second generation sporocysts in the interhepatic lymph sinuses of *Oncomelania hupensis*. Greatly enlarged. (Photomicrograph by Dr. H. E. Meleney.)

and poured out through the duct openings at the head end of the organism. Thus they reach the bloodvessels or lymph nodes, from whence they pass directly to the lungs. In ordinary infections the larvæ pass through the capillaries of the lungs into the heart and out into the systemic circulation, but in overwhelmingly heavy invasions the larvæ may break through the capillaries into the lung tissue and at times into the pleural cavity. Only in such an event is there any possibility of the larvæ attempting to invade the abdominal cavity through the diaphragm, and such an attempt is bound to end in failure since the contents of the cephalic secretory glands (the means of penetration) have been previously exhausted and

are not replenished. From the aorta the majority of the schistosomula in the systemic blood are directed into the vessels feeding the abdominal viscera. Of this number only those entering the mesenteric arteries and passing through to the portal veins are capable of further development. The remainder become lodged in

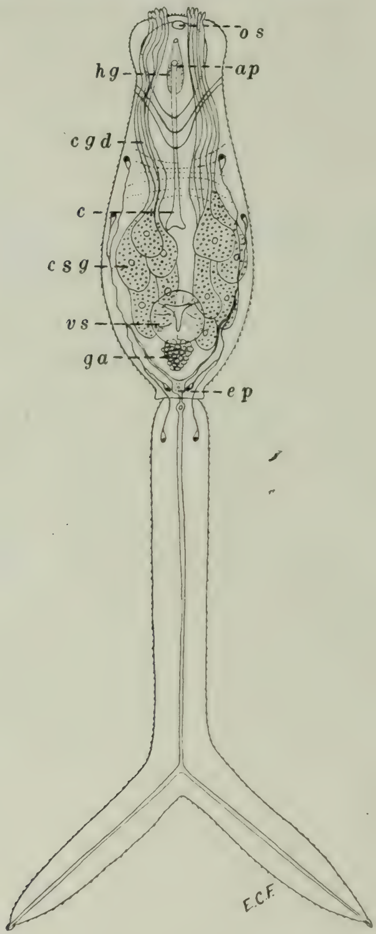


FIG. 50.—*Cercaria of Schistosoma japonicum.* × 340. Lettering as in Fig. 26. (Original.)

small capillaries and are sooner or later digested. By the eighth or ninth day after exposure to infection all of the young flukes destined to enter the portal system have arrived. During the next few days they remain within the intra-hepatic portion of the system, feeding on blood cells and developing rapidly. As they begin to mature they migrate against the blood stream into the mesenteric radicles

where they complete their development and where mating even of the premature worms takes place. At the end of about five weeks after the entry of the cercariæ into the body the worms are mature and the females begin to lay eggs.

Pathological and Clinical Aspects of Schistosomiasis Japonica.—Schistosomiasis japonica or Oriental intestinal schistosomiasis has been known under various names including those of a geographical nature (Katayama disease, Yangtze Valley fever, Hankow fever, Kiukiang fever) and those of symptomatic significance (urticarial fever and neurangiotic edema). In the lesions produced and in its symptomatology this disease closely resembles schistosomiasis mansoni. Both the pathological anatomy and symptoms of the

FIG. 51.—Case of giant urticaria with fever in American youth, six weeks after swimming in infected water in Central China. (Photograph by Dr. H. E. Meleney.)

disease may be separated into the three stages which have been described in schistosomiasis hæmatobia and schistosomiasis mansoni, namely, (1) the period of migration and maturation of the parasite, (2) the period of egg deposition and extrusion and (3) the period of tissue proliferation and repair.

The Incubation Period.—The symptoms during the first stage of the disease are similar to those of the other schistosomiases, although there appears to be evidence that in some cases, at least, urticarial rash, unaccompanied by febrile reaction, may develop as early as five days after exposure to infection. This is about the time when aberrant larvæ become lodged in small bloodvessels, which may be responsible for the reaction. There are abundant data, however, to show that the onset of symptoms, consisting of discomfort in the epigastric region, pains in the back, legs or along nerve tracts, with afternoon fever (38° to 39.5° C.), often associated

with profuse perspiration at night, anorexia, dry hacking cough, and general malaise, occurs about four weeks from the time of exposure. Nausea and vomiting may develop and diarrhea may supervene. The lungs usually show transient areas of dullness associated with slight changes of breath and voice sounds and moist râles. Usually these symptoms and signs are accompanied by an intense urticaria (Fig. 51) with localized edema, involving the subcutaneous tissue. The wheals vary in size from a few millimeters to several centimeters in diameter, are raised, firm, white in color, round or irregular in contour and are surrounded by a broad red areola. They occur on all parts of the body, including the mucous membranes and are attended by intense itching of the affected parts. This condition may last from one day to two weeks. There is usually a leukocytosis at this stage and a more or less intense eosinophilia. Blood is not present in the feces at this period except in very heavy infections. All of the cases in which the early stage of the disease has been studied in China are foreigners. Natives in endemic foci are usually exposed to infection time and again so that infected individuals commonly display several progressive stages of the disease at one time. One epidemic is known, however, in which 40 native school boys, bathing in an infected pool at Anking, Anhwei Province, China, all incurred the infection, the onset of symptoms occurring about a month after exposure. There appears to be little doubt, therefore, in spite of the few cases observed, that this stage of the infection is ordinarily attended by the classical symptoms of schistosomiasis toxemia.

As far as is known the pathological lesions produced by *Schistosoma japonicum* during this stage of migration and maturation of the parasite have been studied only in experimental animals. They consist in (1) definite skin eruption associated with the penetration of the cercaria, which are most conspicuous from the twenty-fourth to the thirty-sixth hour and disappear after eighty-four hours; (2) lesions in the lungs during passage of the parasites through these organs and in intense infections having the gross appearance of diffuse hemorrhagic pneumonia even up to the fourteenth day; (3) lesions in the stomach, kidney and other organs due to escape of the schistosomula from the bloodvessels into the tissues, and (4) hemorrhagic congestion in the liver, spleen and duodenum in heavy infestations during the period of maturation of the parasites.

The Period of Egg Deposition and Extrusion.—The second period of the disease, that of egg deposition and extrusion from the portal vessels into the tissues, immediately succeeds the first stage. It is ushered in by symptoms of dysentery, with eggs of the parasite in the stools. This is accompanied by daily fever and epigastric pain, with tenderness over this area, loss of appetite and weight. The liver is somewhat enlarged and the spleen may be palpable. After

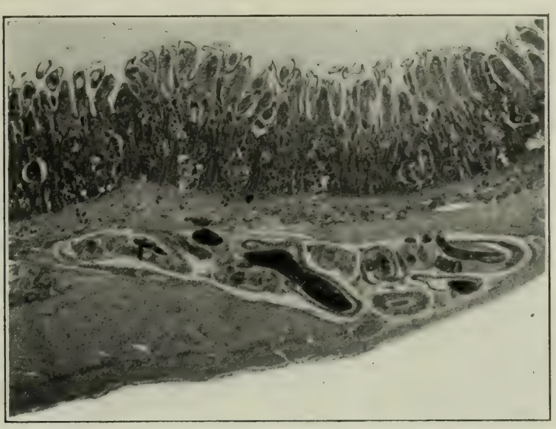


FIG. 52.—Adult males and females of *Schistosoma japonicum* in veins of the submucosa; females depositing eggs which are filtering through the mucosa into the intestinal lumen. (Enlarged from Faust and Meleney, Am. Jour. of Hygiene.)

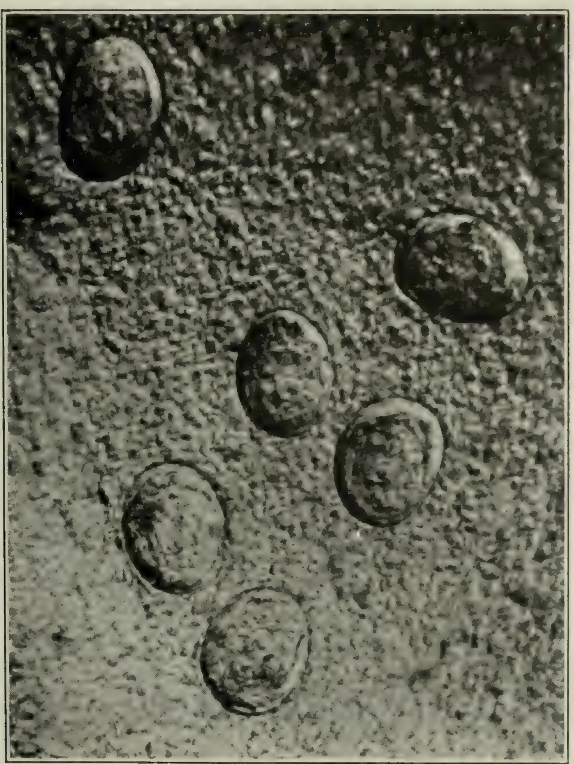


FIG. 53.—Eggs of *Schistosoma japonicum* in bloody mucus exudate from case of acute schistosomiasis japonica dysentery. × 200. (From Faust and Meleney, Am. Jour. of Hygiene.)

a period of three to ten weeks the patient, if untreated, slowly regains his strength, his temperature becomes normal, and he may return to work, although special exertion commonly brings on a recrudescence of the dysentery, and the patient remains underweight. The blood picture is that of a secondary anemia, with a decrease in erythrocytes, a low hemoglobin index and at times a leukopenia.

The primary pathological process responsible for the clinical picture of this stage is the development of multiple lesions around the eggs which have been extruded into the intestinal wall, mesenteric lymph nodes and liver tissue. In the intestine the worms may be found in the vessels of the submucosa (Fig. 52) or even the mucosa, and the eggs are deposited still further distally in the capillaries, so that they are massed into radiating rows in the stoma of the mucosa from the central point in the submucosa, some being situated quite close to the intestinal lumen. Thus the least pressure causes a rupture of the intestinal epithelium and the nearest eggs are extruded into the lumen of the intestine along with blood and mucus (Fig. 53). Congestion first appears in the mucosa and submucosa but later on the serous surface is also involved. Microscopically these lesions center around eggs which come to be surrounded by concentric layers of white cells, conspicuous among which are eosinophils. Thus the typical schistosomiasis abscess is formed. It seldom if ever undergoes necrosis, but frequently breaks through into the lumen of the gut, discharging its contents through small openings between intestinal glands. Repair of injured tissue sets in rapidly, with formation of granulation and scar tissue (Fig. 54). Coincident with this process is the proliferation of glandular epithelium along the periphery of the abscess, so that at times it entirely surrounds the abscess cavity. Meanwhile many of the eggs discharged by the female worm are carried by the blood stream into the liver, where they break through the walls of the vessels into the tissue, there to produce similar schistosomiasis abscesses. These may enlarge, with a degeneration of the more centrally disposed cells and without fibrous-tissue formation on the periphery, or they may become walled off on their periphery by fibroblasts with a definite attempt to encapsulate the egg (Fig. 55). Later on foreign-body giant cells may develop within the pseudotubercles. Along with these changes is the engulfing of small particles of hematin pigment, which had been discharged from the alimentary canal of the parent worms after their digestion of the host's red blood cells, phagocytosed by the endothelial cells of the blood capillaries in the liver parenchyma, by the large phagocytic cells in the portal spaces, and by similar cells in the organizing portion of the pseudotubercles. Congestion of the spleen, with increase of the fibrous reticulum, and enlargement of the mesenteric

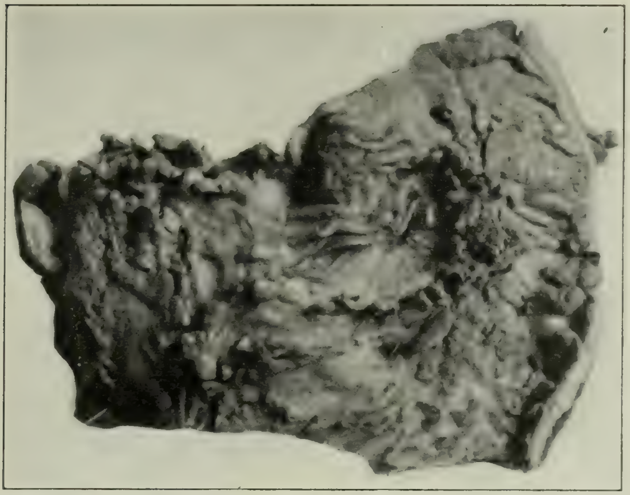


FIG. 54.—Mucous surface of the colon in a case of human schistosomiasis japonica, showing papillomata. (From Faust and Meleney, Am. Jour. of Hygiene.)

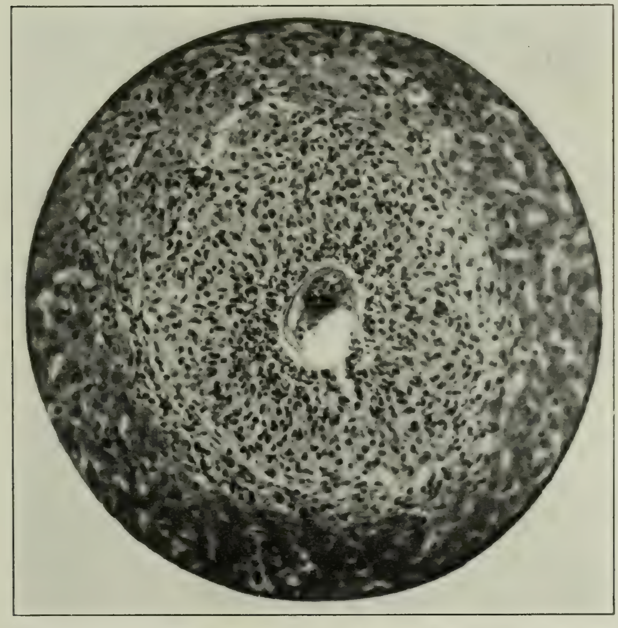


FIG. 55.—Organizing abscess or pseudotubercle around egg of *Schistosoma japonicum* in liver tissue. (From Faust and Meleney, Am. Jour. of Hygiene.)

lymph nodes, with loss of active lymphoid tissue, are also conspicuous features of this stage of the disease.

The Stage of Tissue Proliferation and Repair.—The third period of the infection, that of tissue proliferation and repair, is characterized by cirrhosis of the liver. Since natives in endemic areas are constantly exposed to reinfection the picture of this stage is usually combined with that of the second stage of the disease. In young patients retardation of development both physically and sexually is common. The abdomen on palpation usually reveals an enlargement of liver or spleen or of both organs (Fig. 56). The mesentery

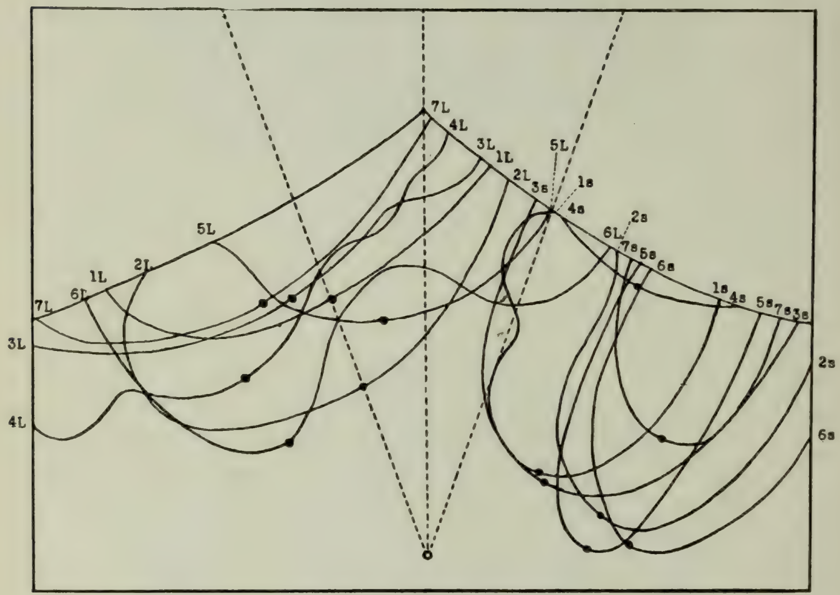


Fig. 56.—Lower margins of liver and spleen in 7 cases of schistosomiasis japonica, second stage. (After Meleney, Faust and Wassell, Journal of Tropical Medicine and Hygiene.)

and omentum are frequently thickened, binding down the colon in a firm mass, so as to present an enlargement in the upper abdomen and another in the lower quadrants, with an intermediate constriction (Fig. 57). Weakness and extreme pallor of the skin are general and dyspnea on light exertion is usually present. Emaciation is often extreme. Ascites is at times relatively slight but is more often pronounced. Dilatation of the veins of the abdomen and thorax is often marked (Fig. 58). The thorax is cone-shaped and the thoracic viscera are frequently pressed upward due to increase of the abdominal contents. Hepatic facies is usually pronounced. The blood-pressure is often subnormal, and the daily temperature

may vary within wide limits. The red blood cells are markedly reduced; the hemoglobin per cent and the color index are both low. Eosinophilia is frequently less pronounced than during the earlier stages of the disease. Precipitin and complement-fixation tests are usually positive, indicating an increase in the blood serum glob-

FIG. 57. — Case of schistosomiasis japonica. Second stage, showing enlarged upper and lower portions of abdomen and constricted middle region. (From Faust and Meleney, Am. Jour. of Hygiene.)

FIG. 58.—Advanced clinical schistosomiasis japonica, with marked ascites, prominent abdominal veins, emaciation, and hepatic facies. (Photograph by Dr. J. H. Foster.)

ulin. The feces frequently consist of poorly digested food, with occasional flecks of blood and mucus, while eggs of *Schistosoma japonicum* are commonly distributed throughout the entire fecal mass. At times they may be so few in number as to be found with difficulty by ordinary smear examination. The development of

ascites is accompanied by a diminution of urine output, but otherwise the urine is usually normal.

Cases with progressive hepatic cirrhosis may go on for many years and only present themselves for treatment in the last stages of the disease. In light infections patients may live for fifteen years or more, although the pathological processes at work during this time undoubtedly shorten the expectation of life and lower the resistance

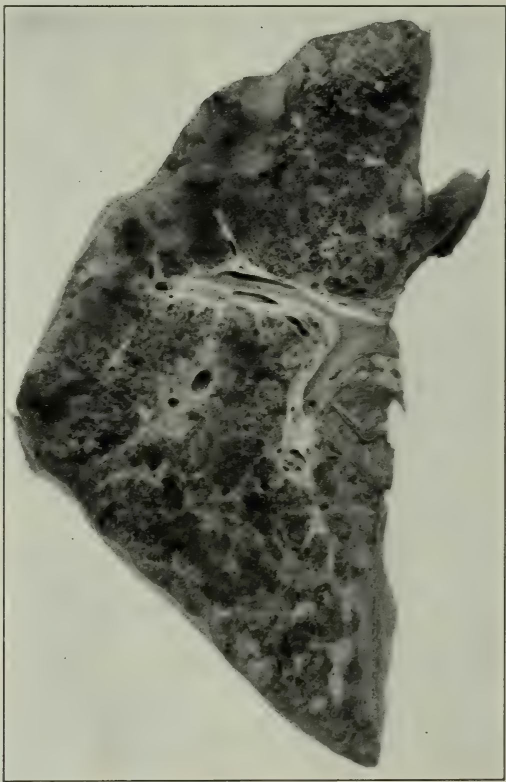


FIG. 59.—Hepatic cirrhosis in human case of schistosomiasis japonica. (From Faust and Meleney, Am. Jour. of Hygiene.)

of the patient to other infections. In repeated infections, there is a consistent decrease in liver function, with the development of marked ascites, which can be only temporarily relieved by abdominal paracentesis. The patient gradually goes downhill and may die of exhaustion, or bronchopneumonia, appendicitis or malaria may hasten the end.

The essential pathological picture of this third period is one of great thickening of the intestinal wall, due to scar formation in all

layers, development of papillomata of the mucosal surface of the gut, shortening and thickening of the mesentery, thrombosis of the mesenteric and portal vessels, and, particularly, hepatic cirrhosis (Fig. 59), brought about (1) by passive congestion in the liver due to embolic closure of many minute portal radicles by eggs, (2) by toxins secreted by adult worms, and (3) by secretions from eggs which are continuously escaping into the portal blood and are being deposited into the tissues. This is the same picture as that described by Symmers for *S. mansoni* infection under the name of "clay pipe-stem cirrhosis." In addition, the spleen is frequently hypertrophied, with a marked increase in the fibrous reticulum and corresponding decrease in the functional cells. In rare cases eggs may reach the lungs in considerable numbers and produce lesions there, or may even wander into the capillaries of the brain, producing symptoms of Jacksonian epilepsy.

Diagnosis and Treatment.—During the period of incubation the disease requires to be differentiated from typhoid fever, while the urticaria must be distinguished from food toxemia and angioneurotic edema. The dysenteric symptoms of the period of egg extrusion must be clearly differentiated from those of bacillary dysentery, intestinal tuberculosis and typhoid fever. Hepatic enlargement with tenderness and epigastric pain necessitate the exclusion of possible amœbic hepatitis. The stage of liver cirrhosis may be confused with idiopathic hepatic cirrhosis or even syphilitic cirrhosis or tuberculous peritonitis with ascites. Pronounced eosinophilia favors a diagnosis of schistosomiasis japonica in persons who have lived in endemic areas, while the recovery of *Schistosoma japonicum* eggs from the feces is definitely diagnostic.

Tartar emetic is specific for treatment of schistosomiasis japonica and is indicated in early and moderately advanced cases. In late cases, where hepatic cirrhosis has proceeded beyond a period of functional recovery of the organ, administration of the drug probably does more harm than good. Sodium antimony tartrate is the drug of choice, and should be administered intravenously in amounts of 1 to $1\frac{1}{2}$ grains (60 to 100 mg., 1 per cent solution) on alternate days, until a total of 25 to 30 grains (1.5 to 1.8 grams) has been administered. If the reaction is severe, as determined by nausea, vomiting and coughing, the interval between doses may need to be increased. The period of treatment therefore amounts to not less than one month and may need to be prolonged to two months or more. Improvement is determined by the gradual betterment of the patient's condition, increased appetite and weight and the gradual receding of the liver and spleen. Stool examination over the period shows a decrease in the number of eggs, their gradual degeneration and final disappearance. The blood picture usually shows a coincident improvement, but eosinophilia and the presence of serum

globulin may persist for some time after the treatment has been completed. On account of the greater involvement of the liver tartar emetic treatment more frequently produces reaction on the part of the patient in cases of schistosomiasis japonica than in those having schistosomiasis hæmatobia. For this reason treatment cannot be feasibly carried out in out-patient clinics. The value of emetine therapeusis in *Schistosoma japonicum* infection is doubtful.

Epidemiological and Prophylactic Considerations.—The areas in the Far East where schistosomiasis japonica is endemic are practically all rice-growing districts. The disease is primarily confined

FIG. 60.—Terminal canal in schistosomiasis japonica endemic area near Soochow, China. *Oncomelania hupensis* in vegetation along banks of canal. (From Faust and Meleney, Am. Jour. of Hygiene.)

to the rice farmers and river boatmen in these districts. The urban population is not seriously involved. However, sportsmen and other visitors to the endemic foci, who wade or bathe in infected water, frequently expose themselves to infection. In Japan, domestic mammals and field mice serve as important reservoir hosts of the infection. In China the only mammal used in infected areas is the water buffalo, which is only incidentally infected because of its thick hide. Sport dogs are occasional reservoir hosts in China.

The infection is found only in the smaller irrigation canals and ditches, either in the rice fields or running up to the homes of vil-

lagers (Fig. 60). The snails involved in the infection are amphibious in their habits, and live at the edge of the quiet canals and ditches, where there is an abundant growth of weeds and grass. This usually occurs in stretches of loam, enriched with humus and fecal débris. The snails are never found in clayey soil or that on which no vegetation is found. Along the canals running through the villages they are most frequently found near containers where night-soil is stored for ripening. From the ditches they become distributed into the rice fields at the time the water is treaded into the fields and develop most prolifically in the rice nursery plots which are heavily fertilized. They are definitely "dirty feeders." In Japan it might be feasible to control the water supply over certain periods, but in China where there is no central authority and each farmer is a law unto himself as far as his crops are concerned, such control is out of the question. Moreover, these snails are operculate and can withstand prolonged periods of desiccation, so that such attempts would produce no diminution in the number of snails. In at least one endemic area in Japan unslaked lime, sprinkled on the banks of irrigation ditches and even in the rice fields has resulted in almost complete destruction of the snails. In China, however, where the areas of infection are manifoldly more extensive, and where only samplings of snails from a few spots have been taken, the vast areas of infected waterways remain unsurveyed.

It is obvious that control of the disease in China by attempts to destroy the molluscan hosts must be preceded by an exact survey of every square foot of ground where the snails are likely to be found. Such a scheme is practically impossible as far as the whole area is concerned but appears to be feasible for certain important endemic foci where the incidence of the disease is particularly heavy. The periodic application of lime along the banks of canals and ditches in such definitely delimited regions will probably be helpful in eradicating the snails. It must be borne in mind, however, that the soil of China is alkaline and that the application of lime to rice nursery beds will injure the ground for intensive use. The addition of copper sulphate solution to canal water is not likely to be successful since the snails are most usually found on the grassy banks above the water surface, but it might prove to be valuable in eliminating the snails from rice plots, particularly rice nursery beds, and at the same time prevent further alkalization of the soil.

In China, however, where man alone is the important definitive host, it seems more likely that success in reduction and ultimate eradication of the disease may be attained by killing the viable ova before they reach the snails. This may be accomplished by educating the farmer population in infected districts to conserve their night-soil long enough to sterilize the ova through fermentation of the medium. In warm weather this occurs in two weeks or less;

during the winter months it would require a longer time. Such a scheme would not greatly reduce the fertilizer value of the night-soil. As has been previously suggested therapeutic prophylaxis for the masses is out of the question in endemic areas of schistosomiasis japonica. Thus it seems most feasible to attempt to break the vicious cycle in endemic foci in Japan, where the areas of infection are circumscribed and where man is only one of several important definitive hosts, by an anti-molluscan campaign; while in China, where the endemic areas are tremendous in size and mostly unsurveyed, and where man is the only important definitive host, the problem of prevention and eradication seems most likely to be successful by centering the campaign on the destruction of the eggs of the parasite in the night-soil before it is distributed onto the fields.

3. **Schistosoma bovis** (Sonsino, 1876) Blanchard, 1895.

Synonyms.—*Bilharzia bovis* Sonsino, 1876; *Gynæcophorus crassus* (Sonsino, 1888) Stossich, 1892.

Schistosoma bovis was discovered by Sonsino in the portal vein of oxen and sheep in the Nile delta in April, 1876, and was later reported by Grassi and Rovelli (1888) in 75 per cent of the native sheep near Catania. It has since been reported from oxen and sheep in Sardinia, Southern France, India, the Malay States, Annam, and South Africa. Cases of infection in man are apparently incidental. There are definite records of human infection in Natal (South Africa), while the cases of intestinal schistosomiasis reported by Chesterman in the Belgian Congo appear to belong to this species. The adult worms have been recently described in detail by Khalil. The eggs may be distinguished from those of *S. hæmatobium* in that they are longer and narrower (170 by 45 μ), with a characteristic terminal spine (See Fig. 14, 4) and always appear in the feces. In South Africa *Physopsis africana* appears to be the appropriate intermediate host. A schistosome cercaria with four pairs of cephalic secretory glands (*C. octadena* Faust, 1921) is believed to be the cercarial stage. The testes in the adult male worm are usually four in number. The parasites and their ova give rise to intestinal schistosomiasis with hepatic cirrhosis.

4. **Schistosoma spindale** Montgomery, 1906.

This parasite, which was first obtained by Montgomery from the mesenteric veins of *Bos indicus* at Muktesar, India, has also been reported from cattle in Sumatra. Its life cycle has been studied experimentally by Liston and Soparkar (1918), who found that kids and guinea-pigs could be infected with the cercariæ which develop in *Planorbis exustus* in the vicinity of Bombay. Fairley and Mackie (1926) have investigated the pathological anatomy of this

Table for the Differential Diagnosis of the Three Common Species of Human Schistosomes.

	S. hæmatobium.	*S. mansoni.*	*S. japonicum.*
ADULTS.			
Male	*length* 10–15 mm. *breadth* 0.8–1.0 mm. *integument* finely tuberculated *testes* large, four	*length* 10–12 mm. *breadth* 1.0–1.2 mm. *integument* grossly tuberculated *testes* small, eight	*length* 12–20 mm. *breadth* 0.5–0.55 mm. *integument* smooth except for minute spines on suckers and gynecophoral canal. *testes* ovoid, compressed seven, in one column.
Female	*length* 20 mm. *breadth* 0.25 mm. *ovary* in posterior third of body, in front of intestinal junction *uterus* contains large number of terminal-spined eggs	*length* 12–16 mm. *breadth* 0.16 mm. *ovary* in anterior half of body in front of intestinal junction *uterus* contains one, at most three or four lateral-spined eggs	*length* 15–26 mm. *breadth* 0.3 mm. *ovary* in middle of body. *uterus* contains many eggs with abbreviated lateral spine.
OVA.			
Size	120–160 x 40–60 μ	140–165 x 60–70 μ	70–100 x 55–65 μ
Shape	oval with conical end	elongated oval	oval to rounded.
Spine	terminal	lateral	lateral.
Exudate from which recovered	usually urine, occasionally feces	usually feces, occasionally urine	feces only, although eggs are found occasionally in bladder wall.
MIRACIDIA.			
Gut	small, short	large, extending over nerve mass	small, short.
Anterior secretory glands	small, short	large, extending to posterior plane of nerve mass	small, short.
Lateral secretory glands	two paired masses with median separation	two-paired masses internally unseparated	two-paired masses internally unseparated.
Cilia at level of excretory pores	interrupted entirely around body	interrupted only at pore opening	interrupted only at pore opening.
CERCARIÆ.			
	S. hæmatobium.	*S. mansoni.*	*S. japonicum.*
Size:			
Body	140–240 x 57–100 μ	140–190 x 50–75 μ	100–160 x 40–66 μ
Tail trunk	175–250 x 35–50 μ	200–260 x 25–40 μ	140–160 x 20–35 μ
Furci	60–100 μ long	50–75 μ long	50–75 μ long.
Anterior sucker	60 μ in transection x 64 μ in length	30–60 μ in transection	33 μ in transection x 54 μ in length.
Cephalic secretory glands*	2 pairs with large nuclei and granular acidophilic cytoplasm; 3 pairs with basophilic reaction (Best's alum-carmine differentiation)	2 pairs with large nuclei and granular acidophilic cytoplasm; 4 pairs with small nuclei and basophilic slime contents (Best's alum-carmine differentiation)	5 pairs with large nuclei and granular acidophilic cytoplasm (not positive to Best's alum-carmine stain).
Cephalic gland ducts	Moderately thick	Very thick	Very thick.
Duct openings	At anterior end of oral sucker; capped by 5 pairs of hollow, piercing spines	At anterior end of oral sucker; capped by 6 pairs of hollow, piercing spines	At anterior end of oral sucker; capped by 5 pairs of hollow, piercing spines.
Head gland	Absent	Absent (?)	One large gland present.
Germ cells	Several large cells posterior to acetabulum	Many cells at posterior end of body	Clustered mass of cells just behind acetabulum.
Second generation. parthenita	Sporocyst	Sporocyst	Sporocyst.
Known hosts	*Bulinus contortus* (Egypt); *Physopsis africana* (Natal); *Physopsis globosa* (Sierra Leone); *Planorbis metidjensis* (Portugal, Morocco)	*Planorbis boissyi* (Egypt); *Planorbis guadeloupensis* (Venezuela); *Planorbis olivaceus* (Brazil); *Planorbis pfeifferi* (S. Africa); *Physopsis africana* (Natal)	*Oncomelania hupensis*, *Katayama nosophora*, *Katayama formosana*.

* Differentiation constantly found in the cercariæ of *S. hæmatobium* and *S. mansoni* from the germ-ball stage to mature cercariæ.

infection, their material showing marked thrombosis of the portal vessels and a periportal cirrhosis. The ova (Fig. 14, 5), which are very long unilateral spindle-shaped objects with a terminal spine, measure from 364 to 400 μ in length by 68 to 72 μ in greatest transverse diameter. They are almost always voided in the feces but in 3.3 per cent of Fairley and Mackie's experimental material, worms were found in the iliac, azygos and renal veins and ova in the bladder wall. The cercariæ are narrower and have longer tail trunks than those of the other mammalian schistosome species. They possess five pairs of cephalic secretory glands, two anterior oxyphilic and three posterior basophilic and an accessory pair of flame-cells. Possible human infections, in which ova resembling those of this parasite were recovered from the urine, have been reported from South Africa (Johannesburg and Zululand).

5. **Schistosoma incognitum** Chandler, 1926.

Chandler has recently (1926) found a non-operculate spined egg (*Schistosoma incognitum*) in human feces from the vicinity of Krishnagar, Bengal and from a Nepalese village, Northern Bengal. The egg somewhat resembles that of *Schistosoma indicum* (Fig. 14, 7) being slightly smaller and less regular in contour. The spine of *S. incognitum* is subterminal and the egg is slightly flattened on the spined side, while in *S. indicum* the egg is regularly oval and the spine terminal.

6. **Cercaria elvæ** Miller, 1923.

This fork-tailed cercaria, the free-swimming stage of a non-human mammalian schistosome, has been recovered from the snails, *Lymnæa stagnalis* var. *appressa*, *L. emarginata-angulata*, and *Physa parkeri*, from Douglas Lake, Michigan, as well as from water in which these infested molluscs have been living. Cort (1928) has shown that this species of cercaria is responsible for papular lesions of the human skin of subjects whose extremities were exposed to water containing the active larvæ. In susceptible individuals (five out of seven) as the water evaporated from the skin a prickling sensation was experienced, followed by the rapid development of urticarial wheals. This condition subsided in about a half hour, leaving only a few macules. Several hours later, however, an intense itching of the region developed, accompanied by edema of the affected member and by transformation of the papules into pustules. The condition was most intense forty-eight to seventy-two hours following exposure, after which time it gradually subsided. Other related species of schistosome cercaria, which are apparently not able to penetrate into the deeper layers of the skin and reach the peripheral bloodvessels of man, may, like *Cercaria elvæ*, conceivably produce a severe local dermatitis.

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CHAPTER XIII.

TREMATODE PARASITES OF THE INTESTINAL TRACT, BILIARY PASSAGES AND LUNGS.

Introduction.—As far as their life cycles are known all of the species of trematodes which are parasitic in the intestinal tract, biliary passages and lungs of mammals gain access to such hosts as encysted adolescariæ (metacercariæ), which are taken in as contaminations of food and drink. The cyst capsule, which has previously been secreted by the cercaria and which enables the larva to pass through the gastric secretions uninjured, is either digested off or weakened by the intestinal juices, so that the activated larva is enabled to break out of its temporary prison house and directly attach itself to the intestinal wall or, if a parasite of the biliary passages, after migration into the common duct and up the biliary tracts, to take up its abode in these outpocketings of the intestine. In the case of *Paragonimus*, the lung flüke, the adolescaria, after excystment in the intestinal lumen, penetrates the intestinal wall and migrates to the lungs, where it develops into the adult worm. The trematodes which have been found in the intestinal tract of mammals belong to the suborders **Monostomata**, **Strigeata** (superfamily **Strigeoidea**), **Amphistomata** and **Distomata**. Only members of the groups **Amphistomata** and **Distomata** are known to be parasites of the human intestine. The parasites of the biliary passages of mammals and the lung fluke, *Paragonimus*, all belong to the suborder **Distomata**.

A. AMPHISTOMATE INFECTIONS OF MAN.

Suborder Amphistomata Bojanus, 1817.

This suborder is an assemblage of families, all grouped under the superfamily **Paramphistomatoidea**, having the acetabulum caudoterminal, subterminal or ventral, close to the caudal extremity.

The amphistomes are generally recognized as consisting of three families, **Paramphistomatidæ**, **Gastrodiscidæ** and **Gastrothylacidæ**, of which some species are parasitic in lower vertebrates, others in avian hosts, but the vast majority live in the intestinal tract of mammals. A very large number of species of amphistomes occurs in domestic and wild ruminants, including cattle, sheep and equines. Two species, *Watsonius watsoni* and *Gastrodiscoides hominis*, have been reported from man.

Family PARAMPHISTOMATIDÆ (Fischoeder, 1901) emend. Stiles and Goldberger, 1910.

This group consists of amphistome species in which there is no ventral pouch.

Genus Watsonius Stiles and Goldberger, 1910. (genus named for Dr. Watson of Northern Nigeria).

1. **Watsonius watsoni** (Conyngham, 1904) Stiles and Goldberger, 1910.

Synonyms.—*Amphistomum watsoni* Conyngham, 1904; *Cladorchis watsoni* (Conyngham, 1904) Shipley, 1905.

Structure and Life Cycle.—This parasite has been reported only once from man, having been found at the autopsy of an emaciated West African negro who died with symptoms of severe diarrhea soon after admission to a hospital in Northern Nigeria. The present author has also found it twice in the cecum of a species of macaque from Singapore. Many of the flukes were seen in the stools of the human case and on necropsy large numbers were found alive and adherent to the wall of the duodenum and upper part of the jejunum. A few were also recovered from the lumen of the large intestine. The living worms were described as pear-shaped bodies, reddish-yellow in color, with a translucent, gelatinous appearance. They were flattened ventrally and were somewhat indented posteriorly at the margin of the large posterior sucker. The specimens when preserved assumed a slaty-brown color.

Watsonius watsoni (Fig. 61) has a length measurement of 8 to 10 mm., a maximum breadth of 4 to 5 mm. and is 4 mm. thick. It is pyriform in shape, being broadest near the junction of the median and posterior thirds of the body. The ventral surface is slightly concave, particularly at the margin of the acetabulum; it is surrounded by a convex ridge which becomes inconspicuous anteriorly. The integument is traversed with transverse ridges. The acetabulum is subterminal and measures 1 mm. in diameter The oral opening is ventro-subterminal and is provided with digitate papillæ; the large oral sucker which lies sunken into the body is about one-fifth as long as the body and measures 1.2 mm. in transverse diameter. It is provided with a pair of latero-posterior pouches. The esophagus, which arises from the inner median aspect of the oral sucker, first proceeds ventrad, then bends abruptly dorso-caudad. The intestinal ceca spring from its posterior outlet, first arching postero-laterad and then proceeding directly caudad to end blindly just behind the anterior margin of the acetabulum.

The excretory system is relatively small and inconspicuous It has been studied only inadequately.

Except for the vitellaria all of the genital organs lie in the mid-

plane of the body between the intestinal ceca. The testes are squarish in contour, with sharply notched fissures; they lie one in front of the other in the mid-third of the body. The two vasa efferentia which arise from the anterior aspect of the testes, unite just in front of the anterior testis to form the vas deferens, which proceeds forward as an intricately coiled tubule. In its more posterior portion the vas deferens is thin-walled (vesicula seminalis *s. s.*), but more anteriad it has a muscular wall. At the forking of the gut it suddenly enlarges into a bulbus, the pars prostatica. On the anterior margin of the bulbus there arises a thin-walled capillary tubule, the ejaculatory duct, which proceeds to the genital papilla. The ovary is a rather small ovate body lying behind the posterior testis and slightly to the left of the mid-line. The oviduct, which arises from its dorso-anterior aspect, proceeds dorsad and then cau-

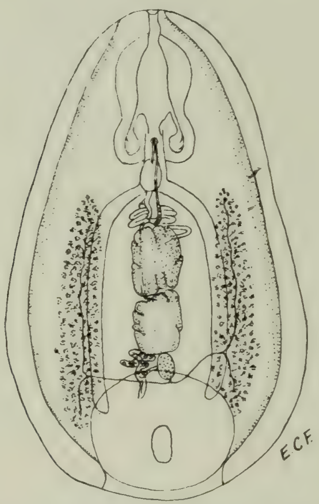


FIG. 61.—Adult specimen of *Watsonius watsoni*, ventral view. × 6. (After Stiles and Goldberger, Hygienic Laboratory Bull. U. S. Marine Hospital Service.)

dad to the oötype, which, with its encompassing shell gland, lies above the ovary. Laurer's canal arises from the dorsal bend of the oviduct and proceeds to the dorsal wall of the worm, where it apparently opens to the exterior. The vitellaria are finely granular aggregations which lie within the antero-posterior confines of the intestinal ceca but are somewhat extra-cecal in their lateral boundaries. Ducts from these glands join to form a common lateral vitelline duct for each side of the body, the two lateral ducts proceeding mesad in the anterior plane of the acetabulum, uniting just behind the ovary and proceeding as a single short duct into the mass of the shell glands, there to join with the oviduct in the forma-

tion of the oötype. No seminal receptacle has been described for this worm. The uterus arises from the antero-ventral aspect of the shell glands and ascends anteriorward by tortuous coilings, being continued from the level of the esophageal fork as the metraterm and, piercing the muscular region of the copulatory apparatus, opens into the genital papilla just posterior to the ejaculatory duct. The eggs, which vary in size from 122 to 130 by 75 to 80 μ, are described as being similar to those of *Paramphistomum conicum.*

The life cycle of the organism is unknown but judging from analogy the cercaria, upon emerging from the molluscan intermediate host, encysts on grass and is thus transferred to herbivores.

Pathogenicity and Symptomatology.—*Watsonius watsoni* causes watsoniasis watsoni. The flukes are attached to the mucosa of the duodenum, ileum and cecum, causing inflammation and sloughing of the mucosa, with scar-tissue formation in chronic cases. The infection gives rise to severe diarrhea and inanition, in some hosts probably terminating fatally. Only one case of infection in man is recorded (Africa).

Diagnosis.—Made by finding eggs of the parasite in the stool.

Therapeusis.—Unstudied. Carbon tetrachloride is probably specific for the infection.

Prophylaxis.—Unstudied. Since the infection is undoubtedly contracted from ingestion of the encysted adolescaria along with food and drink, thorough heating of such food and water will prevent infection.

Family GASTRODISCIDÆ Stiles and Goldberger, 1910.

This group consists of amphistomate species with a discoidal body, divided into a cephalic and a caudal portion.

Genus Gastrodiscoides Leiper, 1913.

(genus from γαστήρ, belly, and δίσχος, disk, with the suffix εἶδος, like or similar).

2. **Gastrodiscoides hominis** (Lewis and McConnell, 1876) Leiper, 1913.

Synonyms.—*Amphistomum hominis* Lewis and McConnell, 1876; *Amphistomum* (*Gastrodiscus*) *hominis* Sonsino, 1895; *Gastrodiscus hominis* Fischoeder, 1902.

Structure and Life Cycle.—This amphistome was discovered and first described by Lewis and McConnell in 1876 from material obtained from the cecum of an Indian patient. The worm was redescribed by Stephens from human material from Assam, and by Leiper, who reëxamined the original material and created the genus *Gastrodiscoides* for it because of the presence of a genital cone and of the absence of papillæ on the venter. The worm has also

been found in man from Cochin China (Brau and Bruyant) and in Indian immigrants in British Guiana. It is said to be common in pigs in Assam. Khalil has described it from *Tragulus napu* from the Malay States.

Gastrodiscoides hominis (Fig. 62) is reddish-orange in color when fresh but becomes creamy-yellow or grayish when preserved. The body is divided into an anterior conical portion and a posterior discoidal region. The worm varies in length from 5 to 10 mm. and in cross section from 4 to 6 mm. In preserved material the anterior

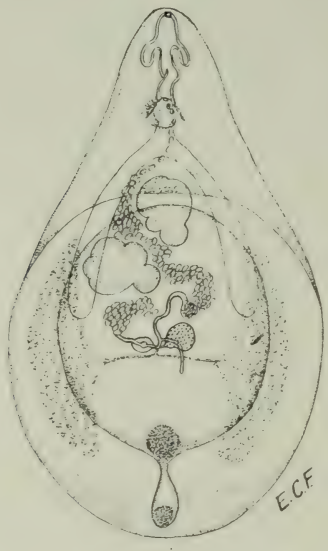


FIG. 62.—Adult specimen of *Gastrodiscoides hominis*, ventral view. × 10. (Original.)

cone measures about 2 mm. in length and is flattened dorso-ventrally. Its junction with the disk is gradual and ill-defined. The prominent genital cone lies slightly behind the mid-plane of the conical portion. The acetabulum, which is situated in the caudal portion of the body, is directed ventrad. It measures from 2.5 to 4.5 mm. in diameter, depending on the amount of its expansion or contraction. The integument is aspinose.

The mouth is situated anteriad. It opens directly into a globular oral sucker. At its slightly constricted posterior margin it gives rise to a pair of lateral pouches and a median prepharyngeal tube. The latter leads into a pharyngeal bulb just in front of the origin of the intestinal ceca. The ceca extend posteriad to the mid-region of the cone, where they end blindly.

The elongate excretory bladder lies in the mid-line dorsal to the acetabulum. Its pore is posteriorly disposed.

With the exception of the anterior portions of the uterus and of

the male duct leading up to the genital cone, the genital organs are all situated in the disk. The testes are large lobate objects situated somewhat obliquely near the anterior margin of the disk. From the anterior aspect of each testis there arises a vas efferens which unites with its mate to form the vas deferens. The latter becomes dilated along its course cephalad to form the seminal vesicle. Both cirrus pouch and pars prostatica appear to be lacking. The male duct opens on the summit of the genital cone just below the female pore. The rounded ovary, which is much smaller than the testes, lies in the center of the disk. Just to its right and slightly posterior in position is the shell gland. Connecting these two objects is the oviduct, with an intermediate outpocketing, which has two branches, one (Laurer's canal) proceeding dorsad and opening to the dorsal surface, the other running anteriad in a slightly serpentine fashion and ending in front of the ovary in a blind pouch, the seminal receptacle. The vitellaria consist of fan-shaped groups of fine follicular particles near the lateral margins of the disk. Their ducts coalesce to form the lateral vitelline ducts, which are horizontal in position and unite on the posterior side of the shell gland and ovary to enter the oviduct just before it proceeds into the oötype. The uterus arises from the right side of the shell gland, coiling first outward then upward, then to the left, from which position it advances in an oblique plane between the testes and then forward to the genital cone. The operculate eggs measure from 150 to 152 μ in length by 60 to 72 μ in cross section.

The fate of this worm outside of the mammalian host is entirely unknown. The related amphistomes, *Gastrodiscus ægyptiacus* and *G. secundus,* have been recovered from the horse in Egypt, and *G. minor,* from the pig in Nigeria and Uganda.

Pathogenicity and Symptomatology.—*Gastrodiscoides hominis* causes gastrodiscoidiasis hominis. The worm lives attached to the mucosa of the cecum and the ascending colon, where it causes inflammation of the mucosa with attendant symptoms of diarrhea. Human infection is relatively uncommon except in Assam.

Diagnosis.—Made by finding eggs of the parasite in the stool.

Therapeusis.—Unstudied. Carbon tetrachloride is probably specific.

Prophylaxis.—Unstudied.

B. DISTOMATE INFECTIONS OF MAN.

Suborder Distomata Zeder, 1800.

This suborder is an assemblage of families having the acetabulum distinctly precaudal and frequently preëquatorial in position. By far the largest number of trematodes parasitic in man is found in this group. All of these species belong to a relatively small number of families which it has seemed advisable to group in the following

superfamilies: **Fascioloidea** Stiles and Goldberger, 1910, *emend.;* **Echinostomatoidea** superf. nov.; **Dicrocœlioidea** superf. nov.; **Heterophyoidea** superf. nov.; **Opisthorchoidea** superf. nov.; **Troglotrematoidea** superf. nov.; and **Hemiuroidea** nom. nov. *pro* **Hemiurida** Dollfus, 1923. The **Fascioloidea** include the families **Fasciolidæ** and **Brachycladiidæ**; the **Echinostomatoidea**, the family **Echinostomatidæ**; the **Dicrocœlioidea**, the families **Dicrocœliidæ**; **Brachycœliidæ**, **Plagiorchidæ** and **Lissorchidæ**; the **Heterophyoidea**, the family **Heterophyidæ**; the **Opisthorchoidea**, the family **Opisthorchidæ**; the **Troglotrematoidea**, the family **Troglotrematidæ**; and the **Hemiuroidea**, the families **Hemiuridæ**, **Halipegidæ**, **Isoparorchidæ**, **Xenoperidæ** and **Azygiidæ**. Other families, of which there are at present no human representatives, may be later allocated to these superfamilies or may prove to be members of entirely new groups.

Superfamily Fascioloidea Stiles and Goldberger, 1910, emend.

This group contains two families, the **Fasciolidæ** and the **Brachycladiidæ**, the species of which obtain transfer to their definitive hosts by encysting in or on vegetation or fishes consumed raw by such hosts. Human representatives are found only in the family **Fasciolidæ**.

Type Family FASCIOLIDÆ Railliet, 1895 (FASCIOLOPSIDÆ Odhner, 1926).

This family consists of only a few known species of large distomes parasitic in herbivorous mammals. Two species of the genus *Fasciola* (*F. hepatica* and *F. gigantica*) and the one recognized species of *Fasciolopsis* (*F. buski*) have been recorded from man.

Genus Fasciola Linnæus, 1758.
(genus from *fasciola*, a fillet).

1. **Fasciola hepatica** Linnæus, 1758.

Synonyms.—*Distoma hepaticum* Linn., 1758; *Distomum hepaticum* Retzius, 1786; *Planaria latiuscula* Goeze, 1782; *Cladocœlium hepaticum* (Linn., 1758) Stossich, 1892.

Structure and Life Cycle.—This fluke, which was the first trematode to be described (Jehan de Brie, 1379), has a cosmopolitan distribution throughout the sheep-raising areas of the globe. It has been reported from the sheep, ox, goat, camel, llama, elephant, horse, ass, rabbit, guinea-pig, squirrel, beaver, deer, roe, antelope, kangaroo, monkey and man. It lives in the biliary passages of the mammalian host, where it produces a disease commonly referred to as "liver rot."

The body of *Fasciola hepatica* is quite large, measuring up to

30 mm. in length by 13 mm. in breadth; it is relatively flat, and leaf like. At the anterior end (Fig. 63) there is a conical projection, 4 to 5 mm. in length, which is usually well differentiated from the broader, flattened leaf-like body. The posterior end is broadly pointed. The integument is spinose. The conspicuous acetabulum, which is near the base of the cephalic cone, measures about 1.6 mm. in diameter, while the oral sucker averages about 1 mm. The intestinal tract, which opens inward from the oral sucker, consists of a well-developed pharynx, a very short esophagus and long intestinal ceca, with secondary and tertiary branches, the ceca extending to the posterior extremity of the worm.

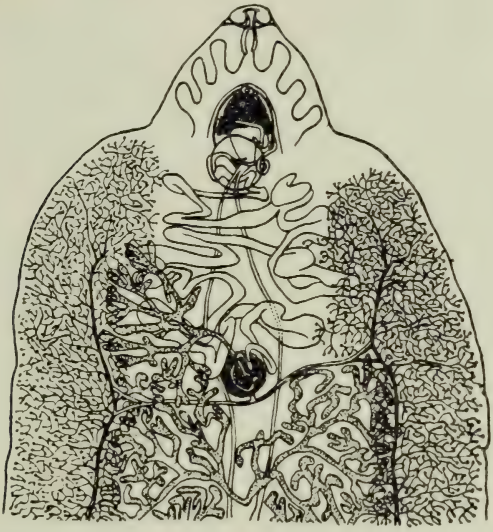


Fig. 63.—Anterior end of adult *Fasciola hepatica*, ventral view. × 6. (After Sommer in Parker and Haswell, Text-book of Zoölogy, Courtesy of Macmillan Company, Ltd.)

The excretory system, although highly complex, is reducible to a simple fundamental pattern.

The genital organs are well-developed. The testes are highly dendritic glands, which are situated one behind the other in the second and third-fourths of the body. From the main anterior stem of each testis there arises a vas efferens which runs anteriad, paralleling its mate, to the region of the acetabulum, where the two ducts unite at the base of the cirrus pouch. Within the pouch three regions may be distinguished: a posterior swollen pocket, the vesicula seminalis, filled with spermatozoa; a median capillary tubule, surrounded by prostate glands; and an anterior muscular region, the cirral organ, which opens into the small genital atrium, and is frequently projected through the genital pore. The female

organs consist of highly branched vitellaria, which lie in the lateral fields, with a main longitudinal duct for each side which has triangular connections with the transverse ducts, the latter joining one another and entering the oötype from the posterior aspect; a highly branched ovary, much smaller than the testes, lying on the right side of the mid-line in front of the anterior testis and opening into the oötype through a short oviduct; a short Laurer's canal, arising from the left side of the oötype and ascending dorsad; the

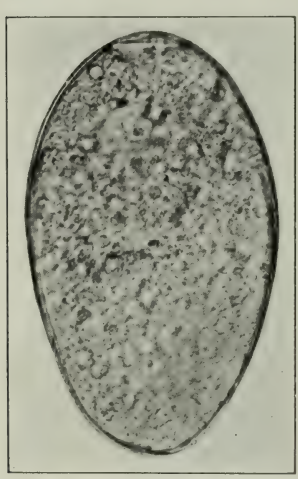


FIG. 64.—Egg of *Fasciola hepatica.* Photomicrograph of egg passed in feces of sheep. × 450. (Original.)

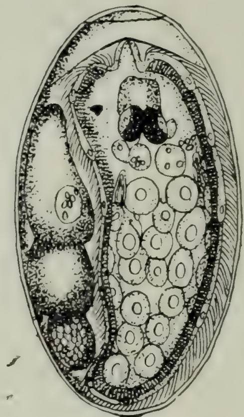


FIG. 65.—Egg of *Fasciola hepatica,* containing fully matured miracidium. × 450. (After Thomas, Quarterly Journal of Microscopical Science, Courtesy of Clarendon Press, Cambridge, England.)

oötype surrounded by a spherical mass of minute unicellular shell glands, and a uterus, which arises from the right side of the oötype anterior to the oviduct and ascends anteriad as a highly coiled meandering tubule toward the oötype. There is no seminal receptacle. The distal extremity of the uterus crosses under the cirrus pouch and opens into the genital atrium at the left of the male organ.

The eggs of *Fasciola hepatica* (Fig. 64) are large operculate objects, having a delicate light brown color; they measure 130 to 145 μ in length by 70 to 90 μ in breadth. Development of the embryo takes place after oviposition. The eggs, which are laid in the biliary tracts, pass into the intestine and are evacuated with the feces.

The development of *Fasciola hepatica,* as first demonstrated by Leuckart and by Thomas, consists in the maturing (Fig. 65) and hatching of the miracidium in a favorable moist environment, its active penetration into the appropriate snail (species of Lymnæa,

Fig. 66), metamorphosis into a sporocyst in the lymph channels of that mollusc, and, with the migration of the sporocysts into the interhepatic lymph spaces, the development (parthenogenetically) of rediæ within the sporocyst. The rediæ, in turn, either produce parthenogenetically other rediæ or the cercarial larvæ of the marital generation (Fig. 67 *A*), which, on maturing, erupt from the snail tissues and swim about in the water, sooner or later encysting in the form of little white spherules (Fig. 67 *B*) on various meadow and swamp grasses and water plants, such as cress. Mammals which graze upon or otherwise consume such herbage contract the infec-

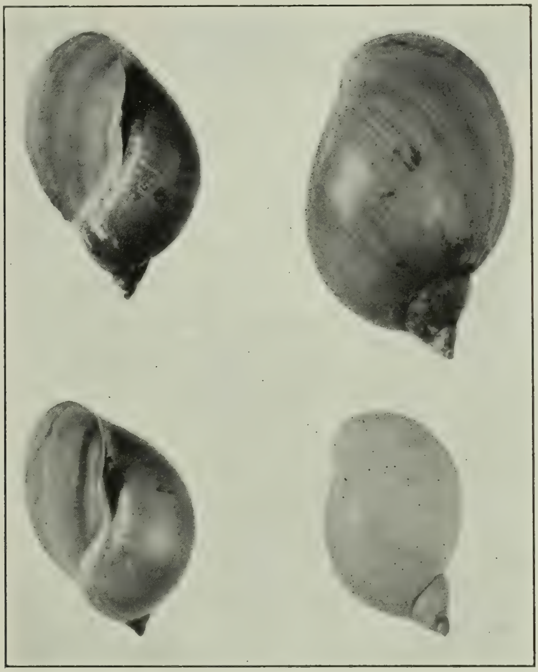


Fig. 66.—*Lymnæa truncatula*, first intermediate host of *Fasciola hepatica* in North China. Natural size. (Original photograph.)

tion, the larvæ (adolescariæ) excysting in the duodenum and migrating up the common duct* into the biliary passages, where they settle down and grow to maturity.

* In "Liver Fluke (*Fasciola hepatica L.*) in the Moscow District" (Repts. Zemstvo Moscow District, No. 14, 1915) D. T. Sinitsin believes he has showed that there are three varieties of the species; that some of the larvæ (adolescariæ) encyst on plants, but that the majority are found in the top 5 mm. of water and some are found in decreasing amounts in lower strata; and that the cysts, when fed to rabbits, hatch out in the intestine, penetrate (?) through the intestinal wall into the body cavity where large numbers are found, and from whence they burrow into the liver, the softest tissue of the abdominal viscera. (This would account for the finding of only adult worms in the region of the gall bladder.)

Pathogenicity and Symptomatology.—*Faciola hepatica,* the liver fluke of the sheep and other herbivorous mammals, causes fascioliasis hepatica or "liver rot." Cases of fascioliasis hepatica in man are relatively uncommon, only about 50 being on record. The encysted larvæ, when taken in as a contamination of water, or ingested with fresh vegetable matter such as blades of grass, or leaves of Rumex, Nasturtium or water-cress, pass through the stomach undigested. On entry into the duodenum the cyst capsule is weakened or digested off and the activated worm emerges. It seems probable that these adolescariæ normally attach themselves to the

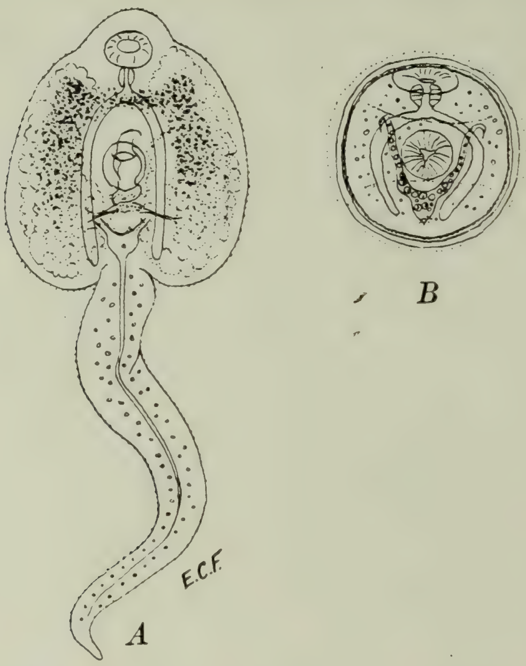


FIG. 67.—*A*, Cercaria of *Fasciola hepatica; B*, encysted metacercaria (adolescaria) of *F. hepatica* from grass in endemic area. × 100. (Original.)

wall of the duodenum in the vicinity of the ampulla of the common duct, migrate into the duct through the pore and up into the biliary passages, the young worms settling down to mature only after they have reached the peripheral biliary capillaries. Here they grow tremendously in size and apparently some of the maturing worms, finding the capillaries too small, return to the larger biliary ducts. Their presence in the biliary passages causes cystic enlargement of the ducts, adenomata of the biliary epithelium, invasion of leukocytes, including many eosinophils, and the eventual development of scar-tissue around the ducts. In heavy infections the epithelium

is eroded and the young worms may invade the liver cells, where abscess pockets are formed. From these pockets the eggs may be extruded into the tissues and set up multiple centers of inflammation. Thus there is a gradual encroachment upon and replacement of the liver cells by scar-tissue, resulting in pressure atrophy of the portal vessels. Brumpt (1922, 1927) recognizes four types of pathological processes produced by the presence of these worms in the biliary passages: (1) destructive, consisting in the ingestion of blood corpuscles; (2) mechanical, causing obstruction of the biliary passages; (3) irritative, resulting in the hypertrophy of the biliary epithelium, enlargement of the passages, and the deposition of sclerified connective tissue in concentric rings around the biliary ducts, with inclusions of ova and detritus; and (4) toxic and bacteriferous action, due to general absorption into the system of toxic by-products and the invasion of bacteria into ulcerated areas. The ingestion of blood cells is practically negligible as far as the effect on the host is concerned. Obstruction of the biliary tracts results in cystic dilatations and in the case of heavy infection produces profound icterus. Irritative action gives rise to pressure atrophy of the hepatic cells and the portal vessels and results in partial or complete cirrhosis of the organ with accompanying ascites. The general toxemia produced by the flukes, especially in heavy infections, results in cachexia aquosa and anemia and is said to be comparable to "bothriocephalus anemia." In such cases a generalized eosinophilia as high as 54 per cent may be produced. Human infection has been recorded from Venezuela, Argentina, France, Hungary, Saloniki, the Dardanelles, and China.

Unusual Foci of Infection with Fasciola Hepatica.—In certain instances specimens of *Fasciola hepatica* have been recovered from abnormal situations in the body, such as the bloodvessels, lungs, subcutaneous abscesses, ventricles of the brain and from foci in and around the eye. The adolescariæ are even believed to pass from the mother to the fetus. Such findings have led certain helminthologists, among them Braun (1925), to predicate that the worms enter the portal system and from there are distributed throughout the body. Although actual proof for this route of migration has not been furnished, it seems to be the most reasonable explanation for the findings of the flukes in these abnormal foci.

In the Lebanon region of Syria a unique infection of man with *Fasciola hepatica* is said to be quite common. It is locally referred to as "halzoun" and consists in the temporary attachment to the pharyngeal mucosa of the adult worms which have been ingested along with raw livers of goats and sheep, used for sacrificial purposes and later eaten. This localized infection produces an edematous congestion of the soft palate, pharynx, larynx, nasal fossæ and Eustachian tubes, accompanied by dyspnea, dysphagia, deafness, and in a few cases resulting in asphyxiation.

Diagnosis.—This is made from the recovery of eggs of *Fasciola hepatica* (Fig. 64) from the stools.

In regions where *Fasciolopsis* is endemic care must be taken not to confuse the two infections, since the eggs closely resemble one another.

Therapeusis.—As far as available records indicate, cases of human infection with *Fasciola hepatica* have not been treated. On the other hand, extensive work on the treatment of fascioliasis hepatica in sheep by Railliet, Moussu and Henry, by Marek, and by various British investigators, including Montgomerie, proves the relatively high efficiency of liquid extract of male fern (*filix-mas*), administered in the amount of 0.1 cc. per kilo of body weight and repeated after twenty-four hours. The drug is given either in capsule or in milk. It is anthelminthic for the large adult flukes, but will not destroy immature worms present in the smaller bile ducts. For the erratic flukes in various foci in the body and for pharyngeal fascioliasis a therapeutic procedure has not been developed.

Prognosis.—Grave in heavy infections. Where only a few worms are present the amount of liver tissue affected is relatively small, with corresponding absence of marked symptoms. The beneficial effect of *filix-mas* therapy warrants its use in all cases where administration is feasible.

Prophylaxis.—Although the distribution of *Fasciola hepatica* infection in sheep is quite cosmospolitan, human infection is relatively rare. Man may also become temporarily parasitized by these flukes from consumption of raw infected livers of sheep or goats, which attach themselves to the pharyngeal mucosa and set up severe local inflammation. On rare occasions the young worms, excysted in the duodenum, may possibly penetrate through the intestinal wall into the bloodvessels or lymph passages and may be carried to such distant foci as the tissues of the eye (*Distomum oculi humani, Monostomum lentis, Distomum ophthalmobium*) or the brain. Care to eat no raw vegetables or drink no unboiled water in endemic foci is an adequate precaution against incurring the hepatic infection. Thorough cooking of infected livers of sheep and goats will prevent thoracic fascioliasis.

2. **Fasciola gigantica** Cobbold, 1856.

Synonyms.—*Distomum giganteum* Diesing, 1858; *Cladocœlium giganteum* (Cobb., 1856) Stossich, 1892; *Fasciola hepatica* var. *angusta* Railliet, 1892; *Fasciola hepatica* var. *ægyptiaca* Looss, 1896.

This fluke (Fig. 68), which is a common parasite of cattle and water buffaloes, and to a lesser extent of other herbivores, lives in the biliary tracts of its host. It has been found frequently in such hosts in Africa and the Far East. There is one record of its occurrence in man, probably contracted in Senegambia (Africa). The

adult fluke is distinguished from *F. hepatica* by its greater length, more attenuate shape, shorter cephalic cone, larger ventral sucker, and by the more anterior position of the testes. The eggs are also larger, measuring 160 to 190 by 70 to 90 μ.

This worm produces lesions in the liver of its host similar to those of *F. hepatica* infection. Diagnosis is based on the recovery of the large operculate ova from the stool. Therapeutic procedure, as tested by Kraneveld on infected cattle and water buffaloes, is similar to that for *F. hepatica*. Prophylactic measures are also identical.

The related giant liver fluke, *Fascioloides magna* (Bassi, 1875), Ward, 1918, which occurs as a parasite in the biliary tracts and lungs of North American herbivores, has not been reported from man.

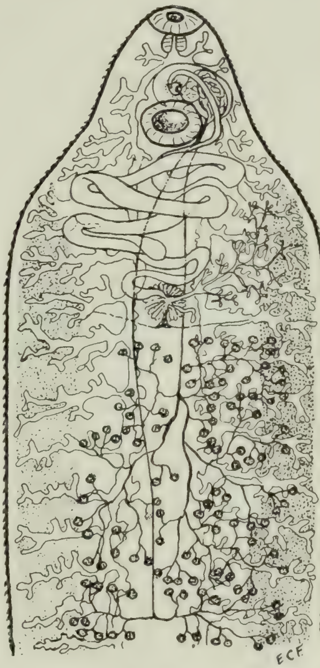


FIG. 68.—Anterior end of *Fasciola gigantica*, showing important organs. × 6½. (Original.)

GENUS FASCIOLOPSIS LOOSS, 1899.
(genus from Fasciola, and ὄψις, resemblance).

3. **Fasciolopsis buski** (Lankester, 1857) Odhner, 1902.

Synonyms.—*Distomum crassum* Busk, 1859; *Distomum rathouisi* Poirier, 1887; *Fasciolopsis rathouisi* (Poirier, 1887) Ward, 1903; *Fasciolopsis fülleborni* Rodenwaldt, 1909; *Fasciolopsis goddardi* Ward, 1910; *Fasciolopsis spinifera* Brown, 1917.

Structure and Life Cycle.—*Fasciolopsis buski* was discovered by Busk in the duodenum of a Lascar sailor who died in London in 1843. The worm was named by Lankester in 1857 and more fully described by Cobbold in 1859. It is the large intestinal fluke of man and the pig in Central and South China, Formosa, Tonkin, Annam, Siam, Borneo, Sumatra, Assam, and Bengal, and probably other parts of the Oriental region.

The body of the worm is large; it may be broadly ovate but is more naturally elongated oval (Fig. 69). Fresh specimens have a pinkish creamy color and are usually somewhat thicker than fasciolid species, averaging about 2 mm. in thickness. They vary in length from 2 to 7.5 cm., and in width from 0.8 to 20 mm. They have a spinose integument, but the spines are easily digested off. There

is no cephalic cone. The acetabulum, which is directed anteriad, measures up to 2 or even 3 mm. in diameter. The oral sucker, at the anterior end, has an average measurement of 0.5 mm. The intestinal tract consists of a very short prepharynx, a bulbous pharynx, and an exceedingly short esophagus which bifurcates in front of the acetabulum to form a pair of unbranched ceca, extending along the medial margin of the vitellaria to the subcaudal end of the worm. The excretory system of the mature worm is complex and has not been satisfactorily studied. The genital pore is immediately preacetabular.

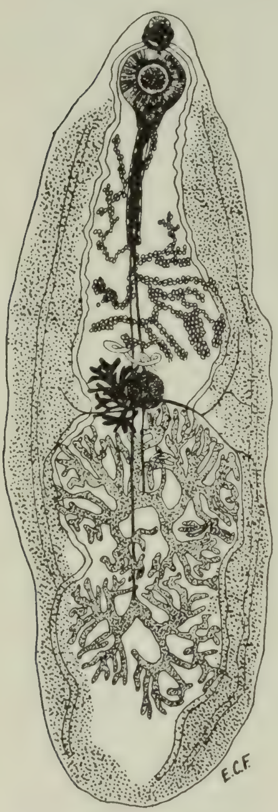


FIG. 69.—Adult specimen of *Fasciolopsis buski*, ventral view. ×4. (After Odhner, Centralblatt f. Bacteriologie u. Parasitenkunde.)

The highly branched testes (Fig. 69) lie one in front of the other in the posterior half of the worm. From the main trunk of each gland a vas efferens arises, passing forward with its mate and entering the cirrus pouch at the point half-way between the oötype and the acetabulum. According to Goddard the elongate tubular cirrus pouch contains the following organs: two seminal vesicles, ejaculatory duct, cirral organ and precirral canal, the latter terminating in the genital atrium. The seminal vesicles are two more or less convoluted tubes, lying side by side within the first portion of the cirrus sac. One of these, the primary vesicle, extends posteriad slightly farther than the other and receives the vasa efferentia. Its distal extremity opens into the secondary vesicle, which narrows to form the ejaculatory duct, which, in turn, continues into the cirral organ, a muscular tubule lined with delicate spines, as is also the precirral canal.

The oötype lies approximately in the middle of the body. It is surrounded by the ovoid shell glands, made up of multiple unicellular glands and encapsulated with connective tissue. The ovary, which lies to the right of the oötype, consists of three main branches, each having several divisions. These open mesad, the lumen being continued into a short oviduct which passes through the shell glands and proceeds toward the posterior face of the oötype, giving off Laurer's canal in its course, and uniting with the common vitelline duct before entering the oötype. There is no seminal receptacle.

The vitelline follicles occupy the lateral fields of the worm, their main longitudinal ducts each having an anterior and a posterior oblique connection with the transverse vitelline duct of that side. The transverse ducts proceed mesad and fuse to form the common duct on the posterior aspect of the shell glands. The distal end of the tubular oötype gives rise to the proximal end of the uterus, which proceeds through a convoluted course, and is continued at the anterior margin of the acetabulum as the metraterm, which opens into the genital atrium. The eggs are ellipsoidal, rounded at both poles, and are provided with a clear, thin shell with a delicate operculum at one end (Fig. 70 *A*). They measure from 130 to 140 μ in length by 80 to 85 μ in breadth. The eggs are laid continuously into the intestinal lumen and are evacuated with the feces.

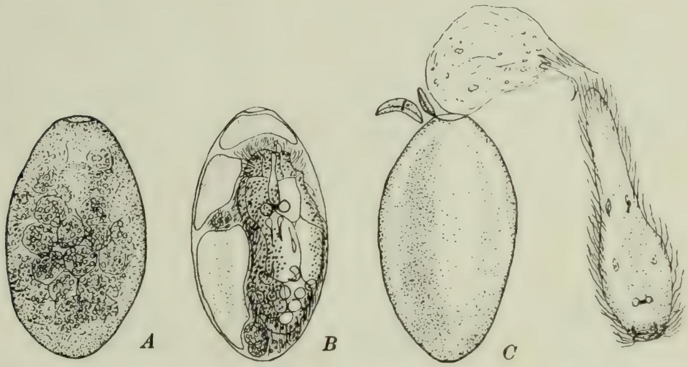
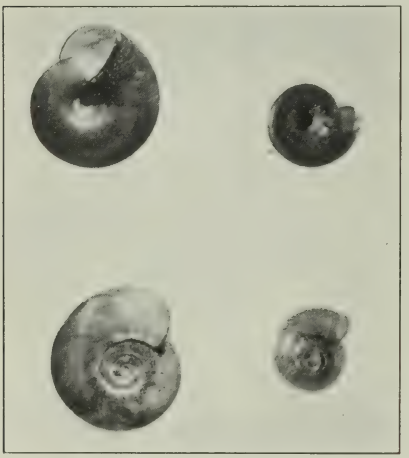


FIG. 70.—Eggs of *Fasciolopsis buski*. *A*, immature egg from feces; *B*, egg with mature miracidium; *C*, miracidium escaping from egg shell. × 200. (After Barlow, Am. Jour. of Hygiene.)

It was at first a matter of considerable controversy as to whether the *Fasciolopsis* from the pig was the same as that of man. Later, due to the different forms and shapes which the worms assume in various preserving media and to differences in the arrangement of the internal organs, particularly the testes, occasioned by the amount of contraction or relaxation of the fluke at the time of its death, several investigators believed that there were several types (designated "species") of *Fasciolopsis* in man. Recent studies, particularly those of Goddard and Barlow in the heavily endemic area around Shaohsing, Chekiang Province, China, have conclusively shown that these flukes from the human host are all one and the same species, while epidemiological and life history data from China and Formosa consistently indicate that the porcine species is the same as that found in man.

The life cycle of *Fasciolopsis buski* was first worked out by Nakagawa (1921), utilizing pigs as the definitive host, and later by Barlow

(1925) in much more detailed study on the human subject. These investigators agree that the life cycle of the large intestinal fluke closely parallels that of *Fasciola hepatica.* The egg of the worm is immature when voided in the feces of the definitive host (Fig. 70 *A*). The miracidium develops to maturity (Fig. 70 *B*) only after the egg has remained for some time (three to seven weeks) in an aqueous medium at a favorable temperature (80° to 90° F.). After maturity of the larva within the egg shell and ripening of the opercular ring the larva escapes from its prison house (Fig. 70 *C*) and actively swims about for a period of six to fifty-two hours, depending on the temperature of the water. In the event that there are snails in the immediate vicinity to which the miracidium is adapted the larvæ attack and penetrate all exposed soft parts of the mollusc. *Planorbis cœnosus, Segmentina nitidella, S. schmackeri,* and *S. hemisphærula* (*largeillierti*) have all been proved experimentally to be appropriate hosts (Fig. 71 *A*, *B*). On entering the snail and reaching the lymph spaces the miracidium becomes transformed into a sporocyst (Fig. 72), which is atypical, in that it possesses a functional rhabdocele gut like a redia but lacks a pharynx. From three to four days later rediæ becomes differentiated within the sporocysts and in nine to ten days emerge free into the lymph spaces. These mother rediæ (Fig. 73) produce only daughter rediæ. It is within these latter that cercariæ develop. Upon maturing (several weeks after the entry of the miracidia into the snail) the cercariæ escape from the daughter rediæ, erupt from the host's tissues and swim vigorously about in the water. However, this period of free-



A B

FIG. 71.—Molluscan intermediate hosts of *Fasciolopsis buski*. *A*, *Segmentina schmackeri*, dorsal and ventral views; *B*, *Segmentina nitidella*, dorsal and ventral views. × 2. (Original photographs.)

FIG. 72.—Sporocyst of *Fasciolopsis buski*, from experimental infection of snail. Greatly enlarged. (After Barlow, Am. Jour. of Hygiene.)

swimming existence is brief, occupying only sufficient time for the cercaria to reach the plant on which the snail is feeding.

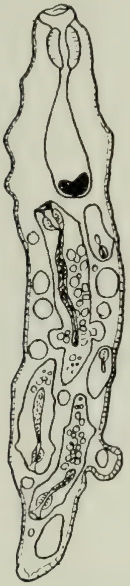


FIG. 73.—Mother redia of *Fasciolopsis buski*, from experimental infection. Greatly enlarged. (After Barlow, Am. Jour. of Hygiene.)

FIG. 74.—Cercaria of *Fasciolopsis buski*. × 300. (Original.)

The cercaria (Fig. 74) is a heavy-bodied, lophocercous larva, with a length over all of nearly 0.7 mm. It has a well-developed triclad digestive tract, a muscular bladder with large convoluted

FIG. 75.—Encysted adolescaria (metacercaria) of *Fasciolopsis buski*. × 370. (After Barlow, Am. Jour. of Hygiene.)

collecting tubules emptying into it, prominent muscular suckers and a spinose integument. As soon as the cercariæ find a suitable spot for encystment, they secrete a viscous substance from their

cystogenous glands. This begins to "set" around the body of the larvæ within one to three hours. Meanwhile the tail has been cast off. The cyst capsule consists of an inner resistant layer and an outer friable one. The cysts (Fig. 75) have an average outer measurement of 216 by 187 microns. Various water plants serve as infective agents (vectors) for man and hogs. The most important of these for man are the water caltrop (*Trapa natans* and *T. bicornis,*

FIG. 76 FIG. 77

FIG. 78

FIGS. 76 and 77.—*Trapa natans*, important infective agent of *Fasciolopsis buski* for man in China. Fig. 76, plant with attached nut. (After Barlow, Am. Jour. of Hygiene); Fig. 77, nut obtained from market in endemic region. Natural size. (Original.)

FIG. 78.—*Eliocharis tuberosa*, the common infective agent of *Fasciolopsi buski* for man. Natural size. (Original.)

Figs. 76 and 77) and the water "chestnut" (*Eliocharis tuberosa,* Fig. 78). *T. natans* has been incriminated in Chekiang Province, China, and *T. bicornis* in Bengal; Eliocharis is probably the major vector in South China (Fukien and Kwangtung) and Formosa, and a minor vector in the Yangtze Valley and Grand Canal region of China.

Man becomes infected with the cysts by eating raw the corms on which the larvæ encyst. The natives usually peel off the "skin"

of the bulbs with their teeth and lips. In so doing they free the attached cysts, some of which are taken into the mouth, pass through the stomach, excyst in the duodenum, and become attached to the intestinal wall, where they grow to adulthood. This period in man occupies about three months, according to experimental human infection by Barlow. The fields where these bulbs are raised are flooded with water, which supplies a favorable habitat

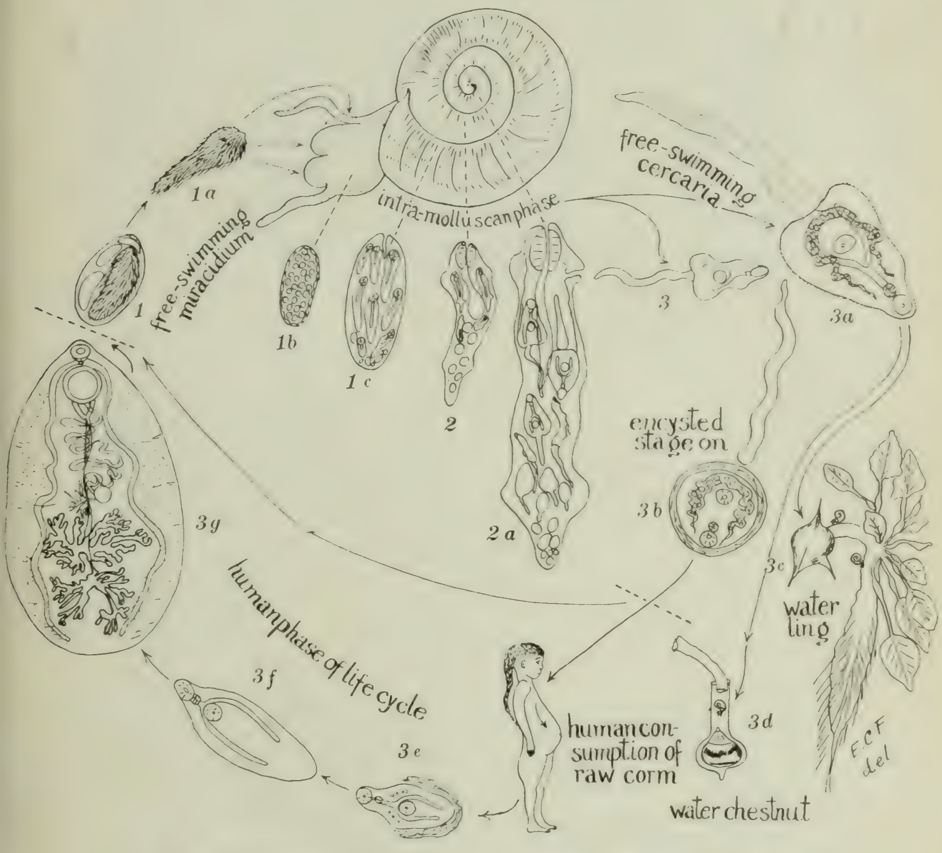


Fig. 79.—Diagram of the life cycle of *Fasciolopsis buski*. (Original.)

for the snails. In endemic areas the beds where these vegetables are grown are either fertilized with infected human night-soil or are contaminated by promiscuous defecation. Since the suitable snails feed on the plant vectors and man later consumes the infected bulbs, the requirements are met for completing the vicious cycle. The life history of the fluke is epitomized in the accompanying diagram (Fig. 79).

Pathogenicity and Symptomatology.—*Fasciolopsis buski* causes fasciolopsiasis buski. The worm usually lives attached to the mucosa of the small intestine, particularly the duodenum, but it may be found attached to the stomach wall, and at times even the

Fig. 80.—Clinical case of fasciolopsiasis buski. Face of patient, showing severe edema of cheeks and orbital area. (From photograph by Dr. C. H. Barlow.)

large bowel. It produces a localized focus of inflammation at the point of attachment. Large numbers of the parasites cause acute intestinal stasis. The lesions occasioned by the presence of the fluke may involve the capillaries of the intestinal wall, producing hemorrhage, or they may provoke abscesses, with infiltration of small round cells and eosinophils. In heavy infections generalized eosinophilia is common.

The first clinical signs come on about three months after exposure to infection.

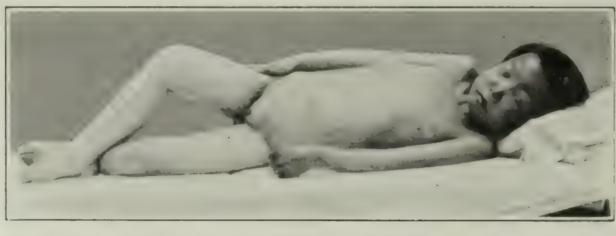


Fig. 81.—Body of same child showing edema of abdominal wall and lower extremities. (From photograph by Dr. C. H. Barlow.)

In light infections mild symptoms such as hypogastric pain, may develop. Larger numbers of the worms produce graver symptoms, simulating gastric ulcer, which are only relieved on taking food. There is usually a diarrhea during the early stage of the infection,

which may, however, be interrupted by periods of constipation. This condition may continue for several months, the patients becoming more and more asthenic, but usually more generalized symptoms develop. The diarrhea becomes more persistent and the stool assumes a greenish-yellow hue, contains much undigested food, and has a disagreeable odor. Edema is an accompaniment of this stage of the disease, involving the face, abdominal wall and lower extremities (Figs. 80 and 81). According to Barlow the chest is not involved save in rare fatal cases. Ascites is common in most instances and in infected children the abdomen is frequently protuberant. On paracentesis many liters of fluid may be withdrawn. During this period generalized abdominal pain is usually noted. The appetite is fairly good, but anorexia, nausea and vomiting may occur and are fairly common accompaniments of heavy infections. There is no true anemia in uncomplicated cases suffering from the disease.

In the terminal stage of the infection the skin becomes harsh and dry, diarrhea is continuous and prostration is extreme. Death results from toxemia following anasarca. Human infection is known from Central and South China, French Indo-China, the Malay States, Java, Burma, Assam, Bengal, and possibly other regions of the Orient. Areas of heavy infection exist in Chekiang and Kwangtung Provinces, China.

Diagnosis.—This is based on the finding of *Fasciolopsis buski* ova (Fig. 70 *A*) in the stool. These must be differentiated from the eggs of *Fasciola hepatica* (Fig. 64), which they closely resemble, from those of *F. gigantica*, which are considerably larger, and from *Echinochasmus* eggs (Fig. 87), which are smaller and somewhat more ellipsoidal. The number of worms in a given infection may be estimated by the Stoll technique (see p. 530), since each mature worm lays about 25,000 eggs per day.

Therapeusis.—Beta-naphthol (2 administrations of 2 cc. each) and carbon tetrachloride (chemically pure, 3 cc. for an adult) are specific for the infection. The latter drug is pleasanter to take and is more effective than the former, but must be used with the greatest care, particularly in heavy infections in children.

Prognosis.—Except in cases of extreme anasarca prognosis is good, provided the patient is afforded specific treatment. The symptoms soon resolve themselves after evacuation of the worms and the patient proceeds to an uneventful recovery.

Prophylaxis.—Human infections may be prevented by thoroughly cooking water-lings and water-chestnuts in endemic areas, or at least immersing suspected corms in boiling water for several seconds. The more fundamental problem consists in the sterilization of night-soil in endemic areas.

Superfamily Echinostomatoidea superf. nov.

This superfamily consists of species which are all placed at present in the

Type Family ECHINOSTOMATIDÆ Looss, 1902.

This family, probably not entirely a natural group, comprises an assemblage of many species, of which life history data are known for only a few. The cercariæ of some forms encyst within their rediæ; others encyst in water after the escape of the cercariæ from the molluscan host; others encyst on vegetation; and still others encyst in the flesh of fishes. The great majority of echinostomes are parasitic in the intestines of lower vertebrates and birds; a few are parasites of the mammalian intestinal tract. Human forms include species of the genera *Echinostoma* and *Echinochasmus.*

Genus Echinostoma Rudolphi, 1809, emend, Dietz, 1910.
(genus from *εχίνος*, spine, and *στομα*, mouth).

4. **Echinostoma ilocanum** (Garrison, 1908) Odhner, 1911.

Synonym.—*Fascioletta ilocanum* Garrison, 1908.

Echinostoma ilocanum was discovered and described by Garrison, who found the eggs in the stools of native prisoners in Manila in 1907, and later, after administration of *filix-mas,* obtained a number of the flukes.

The worm (Fig. 82) is a relatively small elongated oval object, reddish-gray when alive, measuring 4 to 5 mm. in length by 1 to 1.35 mm. in breadth and 0.5 to 0.6 mm. in thickness, the various measurements largely depending on the contraction or relaxation of the worm. At the anterior end there is a circumoral disk, with a breadth of 0.3 to 0.33 mm., separated from the body proper by a slight constriction. The disk is surmounted with a crown of 49 spines, consisting of 5 to 6 spines at each inner ventral angle, lateral to which there are 2 singly disposed spines, then 10 closely set ones, those of each side being united across the dorsum by an irregularly alternating row of 14 spines. Posteriorly the worm is attenuated. The integument is closely covered with plaque-like scales as far caudad as the posterior testis.

The relatively small oral sucker (0.18 mm. in diameter) is situated in the center of the oral disk. The acetabulum (0.4 to 0.46 mm. in diameter) lies in the first part of the enlarged body portion. The pharynx, which is found almost immediately within the oral sucker, measures 170 μ in length by 110 μ in transverse diameter. It leads into a short esophagus, which bifurcates in front of the acetabulum, the ceca proceeding posteriad to the subcaudal region of the body where they end blindly. The excretory system has not been studied.

The testes, which lie one behind the other in the middle of the body, are deeply lobed. Vasa efferentia run forward from the anterior border of each testis to the mid-region of the acetabulum, where they unite into a single deferent duct which enters the cirrus pouch. Posteriorly the pouch contains the vesicula seminalis, which gives rise anteriorly to the long coiled cirral organ, the latter frequently protruding through the genital atrium and out of the genital pore. The prostate is lacking. The ovary is situated in the mid-line slightly in front of the anterior testis. It is transversely compressed. Midway between it and the testis is the oötype, with the enveloping shell glands. The vitellaria are composed of coarse granular masses, which are extra-cecal in position in the middle third of the body but encroach on the ceca in the posterior third. Practically all of the inter-cecal space between the anterior testis and the acetabulum is occupied with the tightly packed coils of the uterus. The operculate ovoid eggs measure from 88 to 111 μ in length by 53 to 74 μ in breadth. They are immature when passed in the feces but are fully developed within six days after culturing.

FIG. 82. — Adult specimen of *Echinostoma ilocanum*, ventral view. × 20. (After Odhner, in Zoölogischer Anzeiger, 1911.)

The exact position of the worms in the gut is unknown. Development outside of the body has not been studied. The presence of these worms in the digestive tract appears to produce no marked intestinal disturbance. *Filix-mas* is a specific therapeutic. It seems possible that mammalian infection may occur from direct encystment of the cercaria on aquatic plants, and their subsequent consumption by man, but infection from raw fish has not been ruled out.

5. **Echinostoma malayanum** Leiper, 1911.

Synonym.—*Euparyphium malayanum* Leiper, 1911.

Echinostoma malayanum (Fig. 83), which was obtained from the intestine of two Tamil coolies at Singapore and at Kuala Lumpur (F. M. S.), closely resembles *E. ilocanum*. It differs specifically in being larger (12 mm. long, 3 mm. broad and 1.3 mm. thick), in having more bluntly rounded ends, in having only 43 circumoral spines (Fig. 84), and in having a cirrus pouch which extends to, if not slightly behind the posterior limit of the acetabulum. The vitellaria are also composed of somewhat smaller follicles and are more extensive in their distribution. The operculate ovoid eggs are

relatively few, brownish in color, and measure from 120 to 130 μ in length by 80 to 90 μ in transverse diameter.

The life cycle of the organism is unknown, but Leiper believes man to be only an incidental host. The clinical aspects have not been studied.

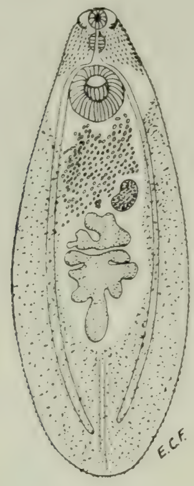


FIG. 83.—Adult specimen of *Echinostoma malayanum*, ventral view. × 8. (After Odhner, in Zoölogischer Anzeiger, 1913.)

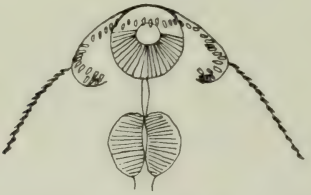


FIG. 84.—Anterior portion of *Echinostoma malayanum*, ventral view, showing circumoral crown of spines. × 30. (After Leiper, Trans. Royal Soc. of Med. and Hygiene.)

FIG. 85.—Adult specimen of *Echinostoma jassyense*, ventral view. × 17. (After N. Léon and I. Ciurea, in Comptes Rendus de la Société de Biologie.)

6. **Echinostoma jassyense** (Léon and Ciurea, 1922).

Synonyms.—*Fascioletta ilocana* Garrison, 1908, of Léon and Ciurea, 1920; *Echinostomum ilocanum* (Garrison, 1908), of Léon and Ciurea, 1920; *Euparyphium jassyense* Léon and Ciurea, 1922.

Echinostoma jassyense was obtained by Léon in 1916 from the diarrheic stools of a patient in Jassy (Roumania) and was first believed to be identical with Garrison's echinostome. The living worm (Fig. 85) was elongate and flattened, reddish in color and meas-

ured 5.44 to 7.60 mm. in length by 1.05 to 1.30 mm. in greatest breadth. The integumentary scales have been observed only on the lateral margins of the worm, extending from the anterior almost to the posterior extremity. The circumoral disk is small, with a width of 0.34 to 0.43 mm. It is provided with 27 spines, of which 4 large ones are situated on each side at the ventral angle and the 19 remaining smaller ones are inserted in a double row without dorsal interruption on the border of the disk. The acetabulum is large and globose, measures 730 μ in diameter and lies some little distance behind the anterior end. The oral sucker is much smaller, averaging about 220 μ in diameter. There is a short prepharynx, a small pharynx, and a capillary esophagus, the gut bifurcating in front of the acetabulum and the ceca extending to the subcaudal region of the worm. The testes, which are situated in the posterior zone of the anterior half of the body, are irregular and somewhat lobate. The cirrus pouch extends somewhat behind the mid-plane of the acetabulum. Its posterior portion is filled with the coiled vesicula seminalis and the anterior portion with the cirral organ, the latter being a long muscular cone. The genital pore opens slightly in front of the acetabulum. The small spherical ovary lies somewhat to the right of the mid-line, midway between the anterior testis and the base of the acetabulum. The vitellaria extend from the plane of the ovary to the posterior border of the fluke. In the pretesticular region these follicles are wholly extra-cecal; more posteriorly they encroach on the ceca and in the posterior half of the worm entirely obscure the ceca. The oötype, with its surrounding shell glands, lies immediately in front of the anterior testis. In front of the oötype and slightly to the left is the seminal receptacle. The uterus fills the space between the primary genital organs and the acetabulum. The operculate ovoid eggs measure 132 to 154 μ in length by 79 to 85 μ in transverse diameter.

Nothing is known of the extra-mammalian phase of the life cycle of this fluke. The clinical aspects of the infection have apparently not been studied.

7. **Echinostoma sufrartyfex** (Lane, 1915).

Synonyms.—*Artyfechinostomum sufrartyfex* Lane, 1915; *Euparyphium malayanum* (Leiper, 1911) of Leiper, 1924 and of Lane, 1924.

Echinostoma sufrartyfex was obtained by a physician on a tea estate in Assam from a girl, aged eight years, suffering from dropsy of the hands and feet and having the general appearance of starvation. One worm was vomited, 5 were passed after administration of santonin, and 57 were passed after administration of *filix-mas*. The flukes, as received in spirit by Lane, averaged 9 mm. in length, 25 mm. broad and 0.8 mm. thick and were curved somewhat ventrad. The description given here is based in part on Lane's study

and in part on cotype material from the Indian Museum studied by the present author.

The whole of the ventral surface of the worm (Fig. 86) and part of the dorsum are covered with sharp spines deeply imbedded in the subintegumentary layer. The spherical acetabulum, which lies well within the center of the anterior third of the body, measures 1 mm. in diameter. There is a more or less pronounced constriction of the body in the region of the acetabulum. At the anterior extremity there is a circumoral disk surmounted by a collar of spines (Fig. 86 *A*), about 39 in number, and all more or less of one size except one pair at the outer ventral angles, which are considerably

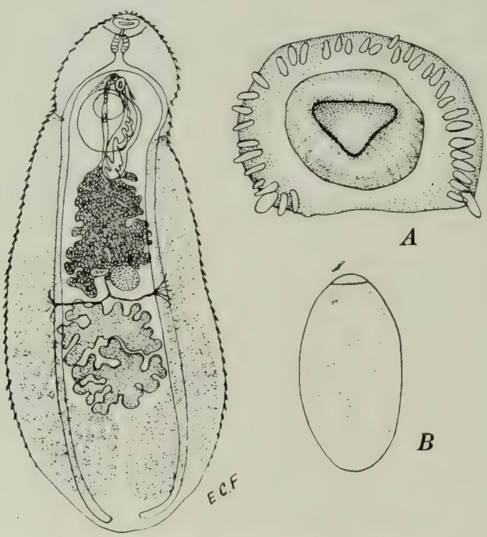


FIG. 86.—Adult specimen of *Echinostoma sufrartyfex*, dorsal view. × 8, (original); *A*, anterior end of body, showing circumoral spines, enlarged, (adapted from Lane); *B*, egg of *E*, *sufrartyfex*. × 190. (Original.)

larger. In the center of this disk is the oral sucker, measuring 0.2 to 0.3 mm., below which is the pharynx of approximately the same size. The latter leads into a short esophagus, which bifurcates almost immediately, the ceca proceeding first laterad, then caudad, and extending to the posterior extremity where they at times curve inward. The deeply lobed testes lie one in front of the other in the posterior half of the body. The vasa efferentia and the vas deferens have not been observed. The cirrus pouch is enormously enlarged, extending from the genital pore in front of the acetabulum more than 0.5 mm. behind the posterior margin of that organ. Within the pouch is an enlarged vesicula seminalis (posteriorly disposed), from the anterior extremity of which there arises the elongate,

tightly coiled tubular cirral organ. Its inner end is surrounded by prostate glands. The ovary is a small subglobose body lying on the right side in front of the anterior testis. At its left is the minute receptaculum seminis. The vitellaria occupy the extra-cecal fields from the region of the acetabulum to the mid-region of the body, where they encroach on the ceca. On the dorsal aspect they converge posterior to the ovary, while the lateral fields closely approximate one another behind the testes. The transverse vitelline ducts proceed mesad just in front of the anterior testis, and on reaching the mid-plane join one another, to continue anteriad to the oötype, uniting *en route* with the oviduct. The uterus, which occupies the inter-cecal space between the ovary and the acetabulum, consists of coils densely crowded on one another. The metraterm opens through a pore, which with the male pore, is situated in a slight depression in front of the acetabulum. The eggs (Fig. 86 *B*) are ovoid and have a well-defined operculum; they measure 90 to 125 μ in length by 60 to 75 μ in transverse diameter, and are immature when laid.

The life history of the worm is unknown. The infection produces a clinical picture similar to fasciolopsiasis. *Filix-mas* is specific for removing the worms.

Echinostoma macrorchis Ando and Ozaki, 1923, a parasite of the intestine of the rat in the Far East, has also been recorded once from man in Kyushu Province, Japan (Majima, 1927).

Genus Echinochasmus Dietz, 1909.

(genus from εχίνος, spine, and χασμυς, hiatus).

8. **Echinochasmus perfoliatus** (v. Rátz, 1908) Dietz, 1910.

Synonyms.—*Echinostomum perfoliatum* v. Rátz, 1908; *Echinochasmus perfoliatus* var. *shieldsi* Tubangui, 1922; *Echinochasmus perfoliatus* var. *japonicus* Tanabe, 1922.

Echinochasmus perfoliatus was first obtained by von Rátz from the small intestine of dogs and cats in Hungary. For some years it has also been commonly found as a parasite of dogs and cats in the Far East. It has also been found in the pig. In 1922 H. Tanabe reported it as a parasite of man in Japan, and proved that human infection resulted from the consumption of certain fresh-water fishes uncooked.

Echinochasmus perfoliatus (Fig. 87) is an elongate worm, measuring from 0.5 to 12 mm. in length by 0.1 to 2 mm. in breadth. The freshly secured living flukes have a creamy color, frequently suffused with a pinkish tinge. Preserved specimens are usually curved ventrad. The entire body is covered with spines. The disk-like acetabulum, which is situated at the posterior limit of the anterior third of the body, is appreciably larger than the oral sucker. The

anterior end of the worm is surrounded by a circumoral disk which is not continuous across the venter. It is surmounted with a coronet of 24 spines, of approximately equal size. These spines (Fig. 87 *A*) are lacking at the mid-dorsum as well as on the mid-ventral surface. The oral sucker is directed antero-ventrad. It leads into a narrow

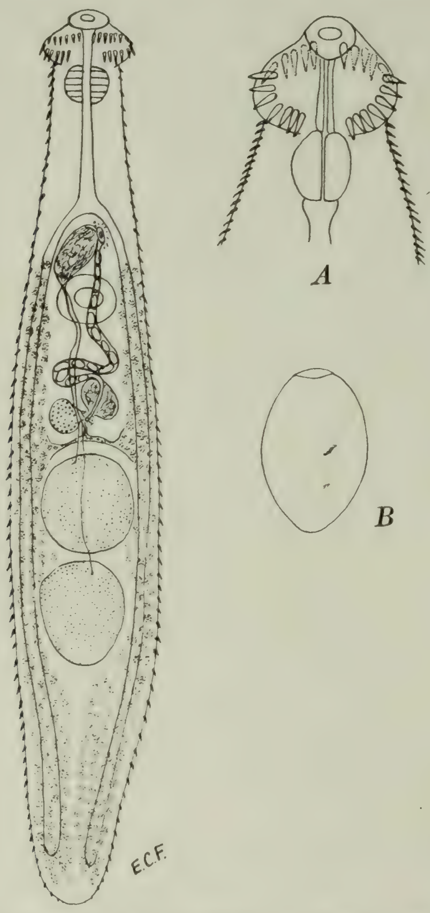


Fig. 87.—Adult specimen of *Echinochasmus perfoliatus*, ventral view, × 30, (adapted from von Rátz); *A*, anterior end of *E. perfoliatus*, showing circumoral crown of spines, enlarged, (after Tanabe); *B*, egg of *E. perfoliatus*, × 212. (Original.)

prepharynx, within which there is a globose pharynx, followed by a long esophagus. The esophagus bifurcates to form the ceca, which extend to the subcaudal portion of the worm.

The testes are large globose or slightly compressed bodies lying one in front of the other in the mid-longitudinal plane just behind

the middle of the body. The vasa efferentia proceed anteriad from the anterior margins of the testes, continuing as delicate tubules over the posterior half of the acetabulum to the cirrus pouch, where they pierce the outer wall of the sac, unite, and become enlarged into the swollen vesicula seminalis. This sperm reservoir completely fills the cirrus pouch, except for a small ejaculatory duct and cirral organ which occupy its anterior portion. The male duct empties into a genital atrium immediately behind the bifurcation of the gut. The ovary is a small globose body lying on the right side of the mid-line and a little in front of the anterior testis. On the left side in a slightly more anterior plane is the receptaculum seminis. The vitellaria extend from the anterior margin of the acetabulum to the posterior end of the body. They occupy the lateral field but more or less encroach on the ceca throughout their entire extent. Transverse vitelline ducts proceed mesad just in front of the anterior testis, unite and continue cephalad for a short distance, joining with the oviduct before entering the oötype. The oötype is a tubular region surrounded by a few shell-gland cells. The uterus originates from its anterior right aspect and proceeds forward as a short, only slightly coiled tubule, over the acetabulum to the genital atrium into which it opens. Only a few eggs (2 to 25) are found in the uterus at any one time. They are ellipsoidal (Fig. 87 *B*), operculate, thin-shelled objects, with a hyaline-greenish hue. They are immature when laid and measure from 90 to 135 μ in length by 55 to 95 μ in transverse diameter.

The extra-mammalian phase of the life cycle is incompletely known. Species of Parafossarulus (*P. striatulus* var. *japonicus* et al.) are considered to be the first intermediate host, while various species of fresh-water fishes (including *Pseudogobio esocinus, Acheilognathus elongatus* and *A. intermedius, Scardinius erythrophthalmus, Abramis brama, Tinca tinca, Esox lucius, Aspius aspius, Idus idus* and *Blicca björkna, Fluvidraco nudiceps, Pseudoperilampus typus, Gnathopogon elongatus, Brevigobio kawabatæ, Pseudorasbora parva, Zacco platypus* and *Z. temmincki, Opsarichthys uncirostris, Mogurnda obscura* and *Chænogobius macrognathus*) have been found by experimental feeding to be natural hosts of the infection. Mammals incur the infection through consumption of raw or insufficiently cooked fish.

Pathogenicity and Symptomatology of Infections With Species of the Family Echinostomatidæ.—The members of this family which have been recorded from man are apparently only incidental human parasites. They reside in the small intestine, usually near the proximal end, where they are attached to the wall by insertion of their spine-encircled oral ends into the mucosa or submucosa. Judging from infections in reservoir hosts they appear to produce no more serious damage than flukes residing entirely in the mucosa.

Small species such as *Echinochasmus perfoliatus* are clinically unimportant except in large numbers. Medium-sized forms, like *Echinostoma ilocanum*, *E. malayanum*, and *E. jassyense*, provoke a moderate catarrhal inflammation of the mucosa. Infection with the more fleshy species, *Echinostoma sufrartyfex*, appears to be accompanied by symptoms comparable to those of fasciolopsiasis. Human infection with all of these species is confined to the Orient.

Diagnosis.—Made on recovering the ova from the stool. These ova are operculate ellipsoidal objects, varying in color from pale yellow to a yellowish-brown, and in size from 88 to 111 μ by 53 to 74 μ for *Echinostoma ilocanum*, from 120 to 130 μ by 80 to 90 μ for *E. malayanum*, from 132 to 154 μ by 79 to 85 μ for *E. jassyense*, 90 μ by 75 μ for *E. sufrartyfex*, and from 92 to 110 μ by 57 to 70 μ for *Echinochasmus perfoliatus*. The eggs contain immature larvæ when evacuated in the feces.

Therapeusis.—Thymol, beta naphthol and carbon tetrachloride are specific drugs for the elimination of these flukes. *Filix-mas* is also effective as a therapeutic when *E. ilocanum* and *E. sufrartyfex* are involved.

Prognosis.—Except in heavy infections the echinostomes are only minor irritating agents of the mucosa. Even in large numbers, save in *E. sufrartyfex* infection, there is no reason for grave concern, although the worms should be eliminated by treatment in order to prevent possible infection from secondary invaders.

Prophylaxis.—In the case of some of these species, eating of raw fresh-water fish should be proscribed; in other cases infection undoubtedly results from eating raw vegetables harboring the encysted larvæ. It is safe to say that the thorough cooking of all food and water would exclude all of these infections from the human intestine.

Superfamily Dicrocœlioidea superf. nov.

This superfamily consists of the families **Dicrocœliidæ**, **Brachycœliidæ**, **Plagiorchidæ**, and **Lissorchidæ**, of which human representatives are found in the

Type Family DICROCŒLIIDÆ (Looss, 1907) Odhner, 1910.

This family contains a large assemblage of species which are characterized by having the testes in front of the ovary. They live in the biliary (and occasionally in the pancreatic) passages of their vertebrate hosts. The majority of the species are parasites of birds. Two species of the family, which are common parasites of domestic mammals, are recorded from man.

GENUS DICROCŒLIUM DUJARDIN, 1845.
(genus from δίχρόος, double, and χοίλία, cavity).

9. **Dicrocœlium dendriticum** (Rudolphi, 1818) Looss, 1899.

Synonyms.—*Fasciola lanceolata* Rudolphi, 1803 (homonym); *Fasciola dendritica* Rud., 1819; *Distomun lanceolatum* Mehlis, 1825; (*Dicrocœlium*) *lanceolatum* (Rud., 1803) Dujardin, 1845; *Dicrocœlium lanceatum* Stiles and Hassall, 1896.

Structure and Life Cycle.—*Dicrocœlium dendriticum*, the lancet fluke, is a common parasite of the biliary tracts of sheep in Europe, Northern Africa, North and South America, Siberia, Turkestan and the Far East. It has also been recorded from oxen, goats, horses and asses, deer, hares, and pigs, and has been found by the present author in camels (North China). It is frequently associated with *Fasciola hepatica* and occasionally with *Eurytrema.* Reported cases from man are few indeed (Germany, Czechoslovakia, Italy, France, Egypt and China) but its presence in man has undoubtedly been overlooked in certain regions where the infection is common in ruminants.

FIG. 88. — Adult specimen of *Dicrocœlium dendriticum*, ventral view. × 10. (Adapted from Braun.)

The worm (Fig. 88) is lancet-shaped and very flat. It measures from 5 to 15 mm. in length by 1.5 to 2.5 mm. in breadth. The posterior end is rounded and the anterior end is attenuate. Its integument is aspinose. The acetabulum, which measures about 0.5 to 0.6 mm. in diameter, lies one-fifth the body distance from the anterior end. The oral sucker is terminal. It leads into a minute globular pharynx and further into a delicate esophagus, which bifurcates some little distance in front of the acetabulum, the ceca proceeding caudad and ending at about the beginning of the terminal fifth of the body. The excretory system consists of a very long tubular bladder (see Fig. 6), with a pore at the posterior end of the body and a pair of lateral connecting tubules, which arise from the antero-lateral aspect of the bladder and proceed latero-anteriad, dividing into anterior and posterior branches in the mid-plane of the ovary. Each branch trifurcates and each fork gives rise to two capillaries, with a flame-cell at the head of each capillary.

The two slightly lobed testes are situated somewhat obliquely between the ovary and the acetabulum. The vasa efferentia arising from the testes ascend side by side to the anterior margin of the

acetabulum, where they join and, entering the bottle-shaped cirrus pouch, enlarge into the coiled vesicula seminalis. This region, in turn, is followed by the pars prostatica, which is terminated by the tubular cirral organ. The genital pore lies under the fork of the esophagus. The subglobose ovary lies to the right of the median line and somewhat in front of the equatorial plane. The small receptaculum seminis lies behind it and Laurer's canal is situated to the left. These several organs open into the oviduct on its way to the oötype. The vitellaria occupy the lateral field in the middle two-sevenths of the body, encroaching upon the ceca in the region where the transverse ducts arise. These latter are directed mesad and, on uniting in the mid-line, proceed anteriad as a short common duct to join the oviduct before the latter enters the oötype. The oötype is a short tubular passage surrounded by a few delicate shell glands. The uterus, which arises from the posterior aspect of the oötype, consists of an intricately coiled tube, which fills the inter-cecal field in the posterior three-fifths of the worm, finally ascending on the left side of the median line and proceeding under the left testis and past the acetabulum to open through the female pore just in front of the male tubule.

The eggs of *Dicrocœlium dendriticum* (Fig. 263 *C*) are thick-shelled and distinctly operculate, with a deep yellowish-brown color. They measure 38 to 45 μ in length by 22 to 30 μ in breadth.

The embryos are usually mature when the eggs are laid, but they do not hatch when placed in an isotonic medium. Leuckart has suggested that normal hatching occurs only after the eggs have been ingested by appropriate snails but repeated attempts on the part of various European investigators to work out the extra-mammalian phase of the life cycle of this worm have been unsuccessful. In view of the fact that the infection is common in herbivorous mammals in endemic areas it seems certain that the cercaria, on emerging from its appropriate molluscan host, encysts on grass, thus providing a means for entry into the definitive host.

Pathogenicity and Symptomatology.—In this infection (dicrocœliiasis dendritica) as in the fascioliases, the presence of the worms in the biliary tracts gives rise to enlargement of the passages, hypertrophy of the biliary epithelium, scar-tissue formation around the ducts, with gradual pressure atrophy of the liver cells and eventual portal cirrhosis. Toxemia is much less marked than in fascioliasis hepatica, probably due to the smaller size of the worms. Only 8 cases of human infection are recorded (Germany, Czechoslovakia, Italy, France, Egypt and North China).

Diagnosis.—Made on the finding of the characteristic ova (Fig. 263 *C*) in the stool.

Therapeusis.—No specific is known. According to Marek *filix-mas* is ineffectual.

Prognosis.—The infection is usually not fatal.

Prophylaxis.—Care not to consume grass, cress or other green herbage from meadows and pasture lands of endemic areas constitutes adequate protection for human beings.

GENUS EURYTREMA LOOSS, 1907.
(genus from εὐρύς, broad, and τρεμα, "sucker").

10. **Eurytrema pancreaticum** (Janson, 1889) Looss, 1907.

Synonyms.—*Distomum pancreaticum* Janson, 1889; *Dicrocœlium pancreaticum* Rail. and Marotel, 1898.

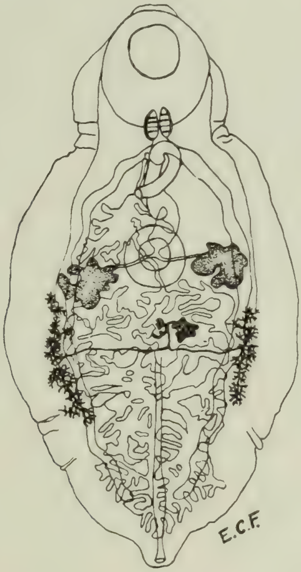


FIG. 89.—Adult specimen of *Eurytrema pancreaticum*, ventral view. × 10. (Original.)

Structure and Life Cycle.—*Eurytrema pancreaticum* (Fig. 89), a common parasite of the pancreatic duct of pigs in Hongkong, and also commonly found in the biliary passages of cattle and water buffaloes in the Orient, and occasionally found in the camel (North China), has been recorded once from man (Hongkong). This fluke differs from *Dicrocœlium dendriticum* in being much stouter and broader, and has slightly ruffled margins. The oral sucker is very large, while the acetabulum is only moderately developed. The deeply notched testes both lie in the posterior plane of the acetabulum, their efferent ducts proceeding mesad and uniting as they enter the cirrus pouch. The cirral organ is long and muscular and is frequently everted far outside the male opening. The ovary is a small notched organ

situated on the side of the common vitelline duct opposite the oötype. The vitellaria are dendritic follicles lying in the third-fourth of the body, at times encroaching on the ceca. The uterus occupies the entire posterior half of the body between the ceca; it also occupies a considerable area anterior to the right testis. The eggs are indistinguishable in size and color from those of *D. dentriticum.*

Pathogenicity and Symptomatology.—This fluke, as the causative organism of eurytremiasis pancreatica in cattle and other herbivores, produces lesions similar to those of fascioliasis heptica. In pigs the worm lives in the pancreatic duct and its out-pocketings, where it gives rise to a hypertrophy of the epithelium and a walling-off of the duct by scar tissue. The only records from man, cited by Castellani and Chalmers, are from South China.

Diagnosis.—Made on the finding of the characteristic ova in the stool. Since these eggs are indistinguishable from those of *Dicrocœlium dendriticum* (Fig. 263 *C*) specific diagnosis can be made from ova only in regions where the latter fluke is not present.

Therapeusis.—Untested.

Prognosis.—Infections are usually light except in pigs. The clinical manifestations are correspondingly mild.

Prophylaxis.—The life cycle of the fluke is unknown, but it seems likely that infection is incurred in a similar manner to that of *Dicrocœlium.* Hence care not to consume green herbage from suspected meadows presumably affords protection against human infection.

CHAPTER XIV.

TREMATODE PARASITES OF THE INTESTINAL TRACT, BILIARY PASSAGES AND LUNGS (*Concluded*).

Superfamily Heterophyoidea superf. nov.

This group contains only the type family **Heterophyidæ** Odhner, 1914, although further information may possibly justify the inclusion of the family **Lecithodendriidæ** Odhner, 1910, and the subfamilies **Microphallinæ** Ward, 1901 and **Gymnophallinæ** Odhner, 1905. These flukes are small, pyriform or elongate organisms, producing very small elliptical eggs, with conspicuous opercula and frequently an abopercular knob-like process. The miracidia, which are bilaterally symmetrical, probably never infect the molluscan host except in a passive way after ingestion of the unhatched eggs by the appropriate mollusc; the cercariæ are oculate lophocercous larvæ, with fluted tail margins; encystment takes place in the flesh of fishes; the adults live in the intestine of vertebrates.

Type Family HETEROPHYIDÆ Odhner, 1914.

This family consists of very small trematodes, oval, pyriform or elongate-oval in contour, with the integument thickly beset with minute scale-like spines. The worms have well-developed oral and ventral suckers, while the genital pore, which is situated near the acetabulum, may be provided with a sucker of its own. The adult worms all live in the small intestine of their host, which is a piscivorous amniote. The small operculate ova contain bilaterally symmetrical miracidia, which are fully mature when laid. Species of Melaniidæ and Bithyniidæ are utilized as first intermediate hosts and fresh-water fishes as second intermediate hosts. The cercariæ are lophocercous oculate organisms which are distinguished with difficulty from those of the **Opisthorchidæ**. Infection of the definitive host results from consumption of infected raw fish.

Genus Heterophyes Cobbold 1866.
(genus from ἕτερος, different, and φυή, shape).

11. **Heterophyes heterophyes** (v. Siebold, 1852) Stiles and Hassall, 1900.

Synonyms.— *Distoma heterophyes* v. Siebold, 1852; *D. heterophyes hominis* Diesing, 1855; *Dicrocœlium heterophyes* Weinland, 1858;

Fasciola heterophyes Moquin-Tandon, 1860; *Heterophyes ægyptiaca* Cobbold, 1866; *Mesogonimus heterophyes* Railliet, 1890; *Cœnogonimus heterophyes* Looss, 1899; *Cotylogonimus heterophyes* Lühe, 1899; *Heterophyes nocens* Onji and Nishio, 1915; *Heterophyes nocens* O. and N., of Cort and Yokogawa, 1922.

Structure and Life Cycle.—This minute pyriform fluke has been found as a natural infection of the cat, dog, fox and man. Its known distribution includes Egypt and the subtropical moist belt of the Far East (*i. e.*, Japan, Southern Korea, Central and South China and Formosa). The worm was discovered by Bilharz from an autopsy in Cairo in 1851 and is now known to be a common parasite of man in the Nile delta, where hundreds of the flukes may be attached to the intestinal mucosa of the human host.

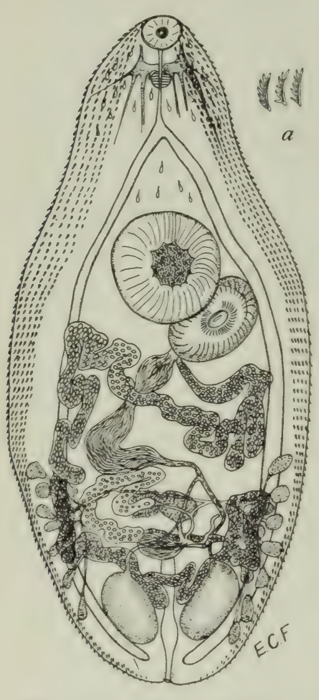


Fig. 90.—Adult specimen of *Heterophyes heterophyes*, ventral view. × 50. (Adapted from Looss); *a*, detail of spines of genital sucker.

Heterophyes heterophyes (Fig. 90) is an elongate pyriform worm, with a broadly rounded posterior and a more pointed anterior end. It measures 1 to 1.7 mm. in length by 0.3 to 0.4 mm. in breadth. The integumentary scales which cover the body are relatively narrow and close to one another; they are more numerous at the anterior end than toward the posterior part of the body. The acetabulum is a very muscular, thick-walled organ situated at the beginning of the equatorial third of the body. It measures 230 μ in diameter. The genital sucker, which lies adjacent to the left posterior aspect of the acetabulum, has an average diameter of 150 μ. Some 60 to 90 chitinous rodlets are set into the genital sucker (Fig. 90). The oral sucker is much smaller, averaging about 90 μ in diameter. It leads into a capillary prepharynx, followed by a minute bulbous pharynx, then a capillary esophagus, which soon bifurcates to form the intestinal ceca, the latter gradually separating from one another until they reach the lateral aspects of the worm, then proceeding posteriad and finally terminating at the rounded posterior part of the body. The excretory bladder is an elongate tube which reaches to the region of the receptaculum seminis, where it receives the lateral collecting tubules.

The two oval testes are situated slightly obliquely, just in front of

the posterior bend of the intestinal ceca. The vasa efferentia are given off from the anterior end of the testes, proceeding forward and mesad and uniting in front of the ovary to form the vas deferens. This common tubule soon enlarges into the coiled retortiform vesicula seminalis, which first bends to the right and then leads into the muscular ejaculatory duct which ascends to the genital atrium within the sucker. It is surrounded near its outer end by prostate glands. Cirrus sac and cirral organ are lacking. The ovary is a subglobose organ, lying in the mid-line near the anterior margin of the posterior third of the body. Its short duct leads posteriad, where it is joined by the receptaculum seminis from the lower right aspect and by Laurer's canal from the lower left. These all lead out through a common duct, first anteriad, then, after receiving the common vitelline duct, proceeding dextrad over the ovary to the oötype. There are about fourteen large polygonal vitelline follicles on either side of the body, of which seven are extra-cecal in position. The oötype, which lies in a transverse position, is surrounded by minute shell glands. The uterus arises from its right aspect, coiling intricately through the intra-cecal field of the worm, and finally ascending to the metraterm beside the male opening within the genital pore.

The eggs (Fig. 91) of *Heterophyes heterophyes* are operculate oval objects with a slight suggestion of a shoulder thickening at the insertion of the opercular cap. They are light brown in color and measure 28 to 30 by 15 to 17 μ.

The life cycle of *Heterophyes heterophyes* is incompletely known. The phase involving the molluscan host has not been studied but it seems probable that invasion of the snail is passive, that the parthenitic generations consist of a mother sporocyst, and one or possibly two generations of rediæ, and that the cercaria is an oculate lophocercous larva, resembling if not identical with *C. pleurolophocerca* Sonsino, which has been found in Egypt in *Melanoides tuberculatus* and *Cleopatra bulimnoides*. On escaping from the snail this larva attacks the mullet, *Mugil cephalus*, where it encysts. The encysted adolescaria (Fig. 92 *A*, *B*) is coiled upon itself. When liberated from the cyst capsule (Fig. 92 *C*) it bears a resemblance to the adult fluke with respect to the shape of its body, the scaly integument and the presence of a genital sucker. Infection of the mammalian host is brought about by consumption of the raw flesh of the mullet and possibly other species of fish. Although the mullet is essentially a fresh-water fish, at the spawning season it is caught in salt-water.

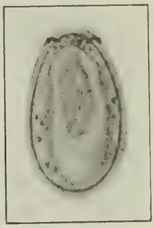


FIG. 91.—Egg of *Heterophyes heterophyes*. × 1200. (After Looss, Thesis Distomum Heterophes und Distomum Fraternum.)

The same species of fish is responsible for the infection (*H. nocens* of Japanese authors) in Japan.

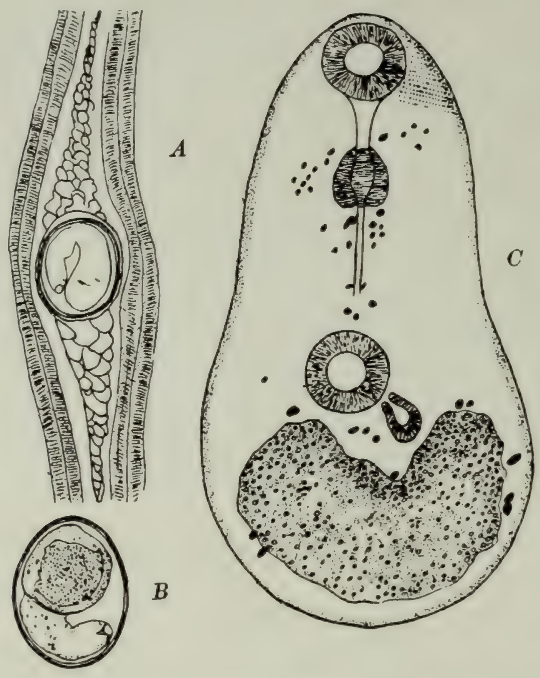


FIG. 92.—Adolescaria of *Heterophyes heterophyes* from flesh of the mullet; *A* cyst between muscles; *B*, cyst dissected out of the flesh; *C*, excysted adolescaria. Enlarged. (After Khalil, Journal of Helminthology.)

12. **Heterophyes katsuradai** Ozaki and Asada, 1925.

Heterophyes katsuradai is a fluke obtained by Katsurada after administration of anthelminthics to patients suffering from diarrhea in the vicinity of Kobe. It differs from *H. heterophyes* in being broader and more rounded in contour, in the enormous size of the acetabulum, in the more posterior distribution of the vitellaria and in the smaller size of the eggs (25.3 to 25.9 by 14.3 to 15 μ).

GENUS METAGONIMUS KATSURADA, 1912.

(genus from *μήτα*, posterior, and *γόνίμος*, genitalia).

13. **Metagonimus yokogawai** Katsurada, 1912.

Synonyms.—*Heterophyes yokogawai* Katsurada, 1912; *Loxotrema ovatum* Kobayashi, 1912; *Tocotrema yokogawai* Katsurada, 1912; *Metagonimus ovatus* Yokogawa, 1913; *Yokogawa yokogawai* Leiper, 1913; *Loossia romanica* Ciurea, 1915; *Loossia parva* Ciurea, 1915;

Loossia dobrogiensis Ciurea, 1915; *Loxotrema ovatum* Kobayashi, 1908 (*erratum*) of Leiper, 1922.

Structure and Life Cycle.—*Metagonimus yokogawai* (Katsurada, June 30, 1912) was first described as *Heterophyes yokogawai* Kats., May 31, 1912, antedating the name *Loxotrema ovatum* Kobayashi October 10, 1912. (*Loxotrema* preocc. [*Loxotrema* Gabb, 1868 Mollusca].) *Metagonimus ovatus* Yokogawa 1913, although originally intended to designate a different species, is also synonymous with *M. yokogawai* (Kats.).

Metagonimus yokogawai is the common heterophyid fluke of the Far East and of the Balkan States. First described by Katsurada from material obtained by Yokogawa from man (Formosa, 1911) and from experimental infection (1911) of dogs and cats with cysts from infected trout (*Plectoglossus altivelis*) and later by Kobayashi (1912) from Korea and by Ciurea (1915) from Roumania, this species has been referred to under a variety of names. The adult worm lives attached to the intestinal mucosa of man, the dog, the cat, the pig, the mouse (experimental) and of the pelican (*Pelicanus onocrotalus*).

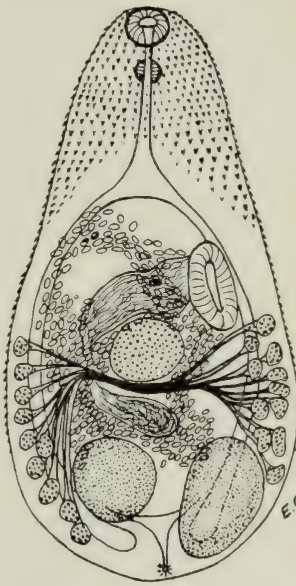


Fig. 93.—Adult specimen of *Metagonimus yokogawai*, ventral view. × 36. (Original.)

The mature trematode (Fig. 93) is very small, measuring 1 to 2.5 mm. in length by 0.4 to 0.75 mm. in breadth. The body is pyriform in contour, rounded posteriorly and tapering at the anterior end, and is provided with a complement of integumentary scales. The acetabulum, which varies from 66 to 165 μ in length by 55 to 114 μ in width is deflected to the right of the mid-line, with its long axis directed diagonally. The oral sucker measures 48 to 110 μ in diameter. It leads into a short prepharynx followed by a globose pharynx (29 to 63 μ in trans-section), then an esophagus, which gives rise to a pair of intestinal ceca ending in the posterior region of the body. The excretory bladder is tubular, with antero-lateral cornua leading up to the proximal ends of the lateral collecting tubules.

The testes lie somewhat obliquely in the posterior part of the body. They are subglobose and are either entire or slightly lobed in outline. Vasa efferentia arising from the anterior border of the testes proceed anteriorward, uniting to form the vas deferens, which expands into the seminal vesicle, the latter being somewhat

retortiform and lying transversely from left to right. The vesicula, in turn, leads into the ejaculatory duct, which is surrounded by prostate glands, and opens, along with the metraterm, into the

FIG. 94. — Egg of *Metagonimus yokogawai*, showing internal organization. × 1300. (Original.)

FIG. 95.—Second generation rediæ of a heterophyid fluke developing in first generation redia. (Drawing by Yokogawa.)

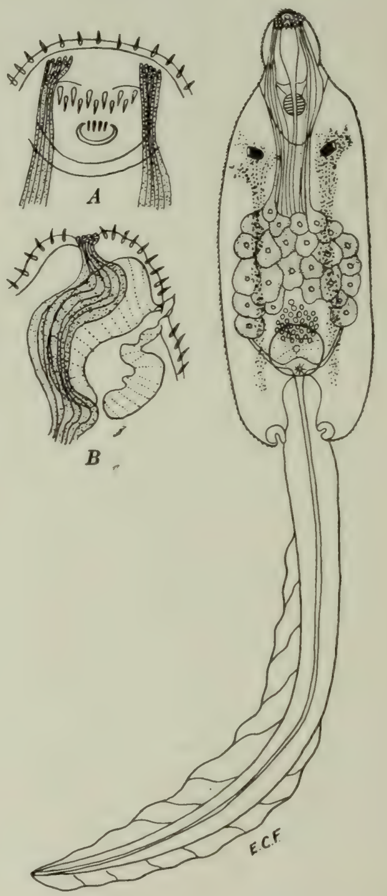


FIG. 96. — Cercaria of *Metagonimus yokogawai*. × 200. *A*, *B*, ventral and lateral views of anterior end of the cercaria, showing oral armature and openings of cephalic gland ducts. Greatly enlarged. (Original.)

genital atrium. The genital atrium, together with the acetabulum, opens into a pit at the anterior border of the latter. The whole acetabulo-genital apparatus is provided with a complex muscular wall. The ovary is a globose body about the size of the testes,

situated in the mid-plane at the anterior margin of the posterior half of the body. Just behind it and slightly to the left lie the retortiform receptaculum seminis and Laurer's canal. The oötype and its enveloping shell glands are situated to the left of the ovary. The vitellaria are coarse and are arranged in a fan-like distribution in the posterio-lateral fields. Collecting ducts assemble toward a common center just behind the oötype, which they enter along with the oviduct after having united into a single vitelline duct. The uterus has an involved course through the inter-cecal field and opens alongside the ejaculatory duct into the genital atrium. The eggs (Fig. 94) are light yellowish-brown, operculate, oval structures, measuring 26.5 to 28 μ in length by 15.5 to 17 μ in transverse diameter. The opercular shoulder is inconspicuous. These eggs can be differentiated from those of *Heterophyes* only with the greatest difficulty. When laid they contain fully mature miracidia, which have a bilaterally symmetrical arrangement of their internal organs.

The first intermediate host of *Metagonimus yokogawai* is *Melania libertina*, *M. ebenina* or an allied molluscan species. The parthenitæ consist of sporocysts (first generation), mother rediæ (second generation, Fig. 95) and daughter rediæ (third generation). The cercariæ (fourth generation) which emerge from the snail (Fig. 96) have an oblong body, attenuated at the anterior end, and are provided with a long lophocercous caudal organ having lateral flutings. The body proper is covered with spines. The acetabulum is situated under the excretory bladder, its muscular elements being poorly developed. In the anterior third of the body on the dorsal aspect there is a pair of pigmented eye-spots. In the vicinity of these eye-spots there are aggregations of golden-brown granules, while posteriad from each eye-spot there is a streak of such granules. The entire subintegumentary layer of the body is also more or less suffused with this pigment.

The anterior end of this cercaria, like that of the cercariæ of other members of the family **Heterophyidæ**, is provided with a peculiar armament, which serves to distinguish it from opisthorchid cercariæ. The oral sucker is anterior in position with its opening slightly ventral. Surrounding the opening are several circlets of strong hook-shaped spines which can be readily distinguished from the smaller integumentary spines. Immediately in front of the oral opening (Fig. 96*A*) are two alternating rows of spines. Projecting from the oral opening is a scoop-like "chitinous lip," with four minute needle-like processes on its incomplete dorsal margin. Some twelve pairs of cephalic glands occupy the middle of the body. Ducts from these glands ascend anteriad and, after passing through the roof of the oral sucker, open through reinforced capillary tubules anterior to it (Fig. 96*A*, *B*). Within the oral sucker is a short

prepharynx, a small globose pharynx and a long esophagus. The ceca are masked by the cephalic glands. The excretory bladder is triangular in shape and has a pair of lateral collecting tubules and an unpaired caudal one emptying into it.

The cercaria, on emerging from its molluscan host, first swims about vigorously through the water, but on finding an appropriate fish in the vicinity, attacks it and penetrates under the scales and into the flesh, utilizing the cephalic gland secretions to digest the host tissue. The most common edible fresh-water fish which is a source of human infection for this fluke is *Plectoglossus altivelis*. On entering the fish, if not before, the tail of the cercaria is discarded. Once within the flesh of the fish or, at times, even under the scales, the larva secretes a cystogenous fluid which "sets" in the form of a more or less spherical capsule around it. The presence of the parasite in the host tissue also stimulates a host-tissue reaction, resulting in the formation of the false outer capsule. The encysted larva grows more or less, depending on the food supply in the immediate vicinity as well as upon the duration of its period of encysted life.

On consumption of the infested raw fish-flesh man and other mammals (or birds) become infected. The outer cyst wall is digested as the food mass passes through the stomach. The inner capsule serves as a safeguard for the parasite until the food reaches the duodenum, when the capsule is weakened by the intestinal juices and the activated larva breaks through the capsule, attaches itself to the intestinal mucosa and develops to adulthood.

Other Heterophyid Parasites of Man.—Other members of the family **Heterophyidæ** which are potential parasites of the human intestine, as determined by experimental feedings, are *Stamnosoma armatum* Tanabe, 1922, *S. formosanum* Nishigori, 1924, *Monorchotrema taihokui* Nishigori, 1924, and *M. taichui* Nishigori, 1924. The first of these species occurs in Japan, the latter three in Formosa. They all involve species of Melania as first intermediate hosts and fresh-water fishes as second intermediate hosts. Infection of the definitive host is incurred through consumption of raw infested fish. Other species of the family, commonly found in birds and mammals, are probably occasional human parasites.

Pathogenicity and Symptomatology of Infections with Species of the Family Heterophyidæ.—The two species of this family which occur as common parasites of the intestinal tract of man and reservoir hosts, *Heterophyes heterophyes* and *Metagonimus yokogawai*, as well as the other species which have been occasionally recorded from man, namely *Heterophyes katsuradai*, *Stamnosoma armatum* and *S. formosana*, *Monorchotrema taihokui* and *M. taichui*, all produce similar lesions in the intestinal wall. The flukes deeply invade the mucous membrane (Fig. 97) where they become attached by their

suckers. At times many eosinophils and leukocytes are seen in the mucous membrane, but no marked pathological change is recognizable. The intestinal epithelium may become slightly atrophied and wide stretches of solitary intestinal glands are occasionally seen. Some flukes, which have invaded the mucous membrane, again come to lie with their heads attached to the surface of this layer. On the whole, the pathological changes due to the presence of these worms are so slight, that the clinical symptoms due to the presence of these species are usually negligible. In cases of heavy infection mild digestive disturbances may result and even persistent diarrhea may develop if extensive stretches of the mucosa are involved. But such cases are believed to be rare indeed and not met with in the ordinary infection.

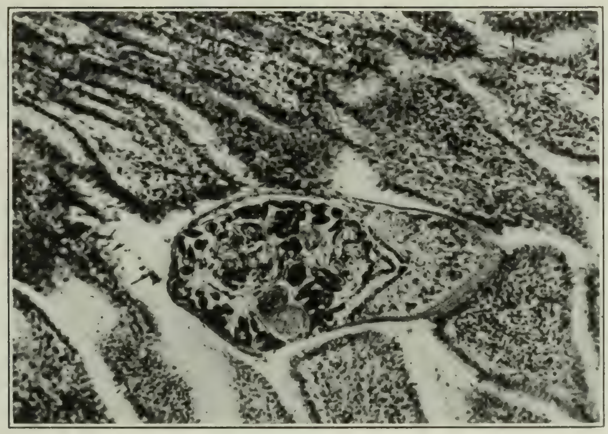


FIG. 97.—Section of ileum, showing position of heterophyid fluke among the villi. × 100. (After Faust and Nishigori, Journal of Parasitology.)

Faust and Nishigori have shown that the heterophyid flukes upon excystment first become attached to the intestinal mucosa in the region of the jejunum, where they grow to adulthood. In the course of time, as they release their hold on the mucosa, they become gradually excreted into the lumen of the intestine along with mucus and other exudates, usually securing a hold further down. In this way they become attached further and further distad, eventually reaching a location where residence is no longer tenable, whereupon they are evacuated in the feces. Thus eventually spontaneous expulsion results, so that the body is free from these flukes, provided reinfection does not occur. These parasites are relatively common in the human population in Egypt (*Heterophyes heterophyes*) and in parts of the Far East (*Metagonimus*.)

Diagnosis.—This is made upon finding the eggs (Figs. 91, 94) of these flukes in the feces. They are minute ovoid objects, with a slight but definite shoulder-thickening into which a curved opercular cap is inserted. They are fairly thick-shelled, and at the abopercular end possess a short knob-like extension or an internal thickening. Their color is a pale yellow, varying from lemon to a champagne hue.

They vary in size from 20 to 35 μ in length by 11 to 20 μ in width, depending on the species. Each egg has within its shell a bilaterally symmetrical larva, well developed at the time the egg is laid. The eggs of these flukes are frequently confused with those of *Clonorchis sinensis* (27 to 30 by 15 to 17 μ) and *Opisthorchis felineus* (30 by 11 μ) the two latter, however, possessing an asymmetrical arrangement of the internal organs of the larva. On account of the greater significance attached to the presence of *Clonorchis* or *Opisthorchis* ova in the stool, differentiation of these two groups of ova is important.

Therapeusis.—Although there is fairly good evidence that in the course of time the heterophyid trematodes will be spontaneously evacuated from the bowel, it is sometimes desirable to expel them with anthelminthics. Thymol, beta-naphthol or carbon tetrachloride is recommended for this purpose.

Prognosis.—Good.

Prophylaxis.—Infection in man may be prevented by thoroughly cooking all fresh-water fish to be consumed.

Superfamily Opisthorchoidea superf. nov.

This superfamily consists of flukes having an elongated body, which is usually flat, transparent and flabby. The suckers are close together and are relatively weak. The integument of the adult worm may be aspinose (*Opisthorchis, Clonorchis*) or beset with spines (*Metorchis*). The genital pore, which is immediately in front of the acetabulum, is provided with only a weak sphincter. The adult worms live in the biliary passages of their hosts, but in cases of overwhelming infection may invade the pancreatic duct. Piscivorous amniotes serve as the definitive hosts. Some members of this superfamily live in mammals, others in birds, but there appears to be less choice in the matter of such hosts than obtains for the **Heterophyidæ**. The small operculate eggs have a distinct shoulder-thickening at the insertion of the operculum. They contain, when laid, mature miracidia which have an asymmetrical arrangement of their internal organs. Species of bithnoid snails serve as the first intermediate hosts of *Clonorchis*, the only member of the superfamily of which the like cycle has been fully studied. The lophocercous eye-spotted cercariæ closely resemble those of the **Heterophyidæ** but can be distinguished by the absence of the oral spinose armature. Practically any species of fresh-water fish may serve as second

intermediate host. Infection of the definitive host results from consumption of the infected raw fish. All of the known species of this group belong to the:

Type Family OPISTHORCHIDÆ Lühe, 1901.

This family has the characters of the superfamily.

GENUS OPISTHORCHIS R. BLANCHARD, 1895.
(genus from *ὄπισθεν*, posterior and *ὄρχις*, testis).

14. **Opisthorchis felineus** (Rivolta, 1884) Blanchard, 1895.

Synonyms.—*Distoma conus* Gurlt, 1831, *nec* Creplin, 1825; *D. lanceolatum felis cati* v. Siebold, 1836; *D. felineum* Rivolta, 1884; *D. lanceolatum canis familiaris* van Tright, 1889; *D. sibiricum* Winogradoff, 1892; *D. winogradoffi* Jaksch, 1897.

Structure and Life Cycle.—*Opisthorchis felineus* is the lanceolate fluke commonly found in dogs and cats in Central and Eastern Europe. It has been described from man in Prussia and Siberia, where it is common. The first human cases were reported by Winogradoff from Tomsk (1892). There are also records of its occurrence in India, Japan and Tonkin (French Indo-China) but it has not been proved to occur endemically in the Sino-Japanese area where *Clonorchis* is prevalent.

The adult worm (Fig. 98) is a lance-shaped trematode, rounded posteriorly and tapering anteriorly. It measures from 7 to 12 mm. in length by 2 to 3 mm. in breadth. Its thickness is only a small fraction of its breadth. On being freshly removed from the biliary tracts the fluke is permeated with a reddish or reddish-orange hue. The integument is aspinose in adult worms but immature forms may still possess spines. The acetabulum which measures about 250 μ in diameter, lies about one-fifth the body distance from the anterior end. The oral sucker, which has the same measurement as the acetabulum is subterminal and is directed antero-ventrad. It leads directly into a small bulbous pharynx, which is followed by a very short esophagus, the latter bifurcating almost immediately to form the ceca, which extend almost to the posterior end of the worm. The excretory bladder is a long tubule, occupying the mid-line in the posterior fourth of the body. The pore is terminal. There is an anterior median pocket in front of the openings of the pair of lateral collecting tubules.

The testes are lobed glands situated obliquely in the posterior fourth of the worm, one to the right and one to the left of the excretory bladder. The two vasa efferentia arise from the anterior aspect of the testes and in the equatorial region of the body unite into a common vas deferens which ascends anteriad, enlarging *en route* into the slightly coiled vesicula seminalis, which terminates in a

weakly muscular ejaculatory duct. The latter proceeds directly to the genital atrium. There is no cirrus pouch. Prostate glands and cirral organ are also lacking. The ovary is a small oval or slightly lobed body lying in the mid-plane slightly in front of the anterior pouch of the excretory bladder. Behind it are the retortiform receptaculum seminis (left) and Laurer's canal (right). Immediately to the right is the oötype, with its surrounding aciniform shell

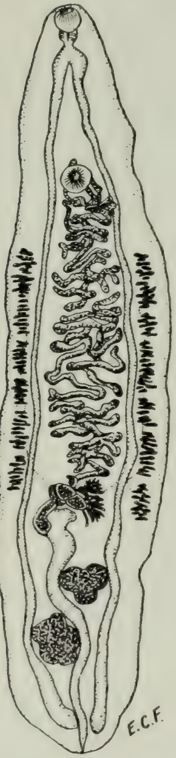


FIG. 98.—Adult specimen of *Opisthorchis felineus*, dorsal view. × 10. (After Stiles and Hassall, Hygienic Laboratory Bull., U. S. Marine Hospital Service.)

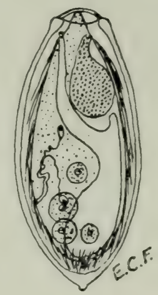


FIG. 99.—Egg of *Opisthorchis felineus*. × 1200. (After Faust and Khaw, Am. Jour. of Hygiene.)

glands. The vitellaria, which consist of many transversely compressed follicles, occupy the extra-cecal fields in the middle third of the body. The collecting ducts proceed postero-mesad and unite into a short common vitelline duct, which joins with the oviduct before entering the oötype. The uterus arises from the anterior aspect of the oötype and proceeds anteriad as an intricately coiled tubule, terminating in the metraterm which opens into the genital atrium beside the male tubule.

The eggs of *Opisthorchis felineus* (Fig. 99) are elongate oval objects approximately three times as long as broad (30 by 11 μ). They possess an operculum which fits into a shouldered thickening of the shell proper. The miracidium is fully mature when the egg is laid. Its internal organization is asymmetrical. The method by which the molluscan host is infected and the species of molluscs which is utilized are unknown, as are also the parthenital and cercarial phases of the life cycle. However, the cercaria is certain to be a lophocercous oculate larva, closely resembling that of *Clonorchis* (Fig. 107). Likewise its method of invading the piscine second intermediate host is probably similar to that of the *Clonor-*

chis cercaria. The adolescaria has been found encysted in *Leuciscus rutilis* and *Idus melanotus* in Eastern Prussia and in *Tinca tinca* in Roumania. Infections of mammals occurs from consumption of infested raw fish-flesh.

15. **Opisthorchis viverrini** (Poirier, 1886) Stiles and Hassall, 1896. *Opisthorchis viverrini* (Fig. 100), which was first described from the civet cat, *Felis viverrus*, was twice recovered by Kerr from autopsies

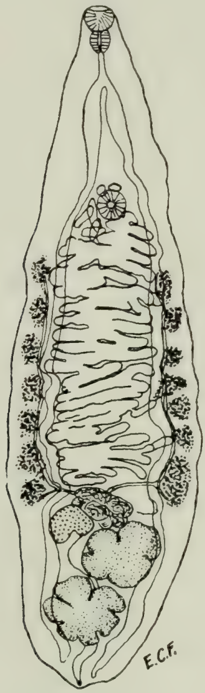


Fig. 100.—Adult specimen of *Opisthorchis viverrini*, ventral view. × 10. (After Leiper, in Jour. Royal Army Med. Corps, Courtesy of John Bale Sons & Danielsson, Ltd.)

in Northern Siam and is known to be present in about 25 per cent of the population of the Lao country, as determined by stool examination. This species differs from *O. felineus* in the greater proximity of the ovary to the testes, the different type and distribution of the vitellaria and the greater tendency of the testes to form deep lobules. The eggs are also shorter and broader (26 by 13 μ), in this respect being more like *Clonorchis* ova. Infection is undoubtedly incurred through consumption of infested raw fish.

16. **Opisthorchis noverca** Braun, 1902.

Synonyms.—*Distoma conjunctum* Lewis and Cunningham, 1872; *Amphimerus noverca* Barker, 1911.

Opisthorchis noverca, which was first found in the biliary passages of Indian pariah dogs by Lewis and Cunningham in 1872 and two years later by McConnell at the autopsy of two Mohammedans, differs from *O. felineus* and *O. viverrini* in the small size of the acetabulum compared with the oral sucker and the close approximation of the two suckers, the greater distribution of the vitellaria and the much larger eggs, which measure 34 by 21 μ. The fluke has also been reported from the wolverene.

Genus Clonorchis Looss, 1907.

(genus from χλών, branched, and ὄρχίς, testis).

17. **Clonorchis sinensis** (Cobbold, 1875) Looss, 1907.

Synonyms.—*Distoma sinense* Cobbold, 1875; *D. spathulatum* Leuckart, 1876; *D. hepatis innocuum* Baelz, 1883; *D. hepatis endemicum* Baelz, 1883; *D. hepatis perniciosum* Baelz, 1883; *D. endemicum* Ijima, 1886; *D. japonicum* Blanchard, 1886; *Opisthorchis sinensis* Blanchard, 1895; *Clonorchis endemicus* Looss, 1907, *pro parte; C. sinensis* var. *major* Verdun and Bruyant, 1908; *C. sinensis* var. *minor* Verdun and Bruyant, 1908.

Historical.—*Clonorchis sinensis,* the Chinese liver fluke, was first found by McConnell in 1874 in the biliary tracts of a Chinese carpenter in Calcutta and was described by him the following year. The discovery of the worm in Japan occurred in 1875, although it was not described until 1883, when Baelz recognized both a pathogenic variety (*D. hepatis perniciosum*) and a harmless one (*D. hepatis innocuum*). Various records of the fluke in Chinese patients abroad appeared from 1877 to 1907 but the first information on the infection in the endemic area in China was not published until 1908 (Heanley). The distribution of this fluke is confined to the Sino-Japanese areas (Fig. 101), where man, dogs, cats, wild cats, hogs, martens, badgers, minks and guinea-pigs have been found to be naturally infected. The endemic area extends throughout Japan, Korea, China (except the northwest), Formosa, and French Indo-China, although heavy foci of human infection are confined to the Okayama district in Japan, Southern Korea, parts of Kwangtung Province, China, and the delta of the Red River in Tonkin (French Indo-China).

Structure of the Adult Worm. The adult fluke (Fig. 102) is a spatulate worm, tapering anteriorly and somewhat rounded posteriorly. It is flat, transparent and flabby. The two species (*C. sinensis* and *C. endemicus*), which were created by Looss purely on size differences, are now recognized as a single valid species, with a size range from 10 to 25 mm. in length by 3 to 5 mm. in breadth.

The integument of the adult worm is aspinose. The small acetabulum is situated at the beginning of the second fourth of the body. The oral sucker, which is slightly larger and more muscular than the acetabulum, is directed anteriad. Immediately behind it lies the

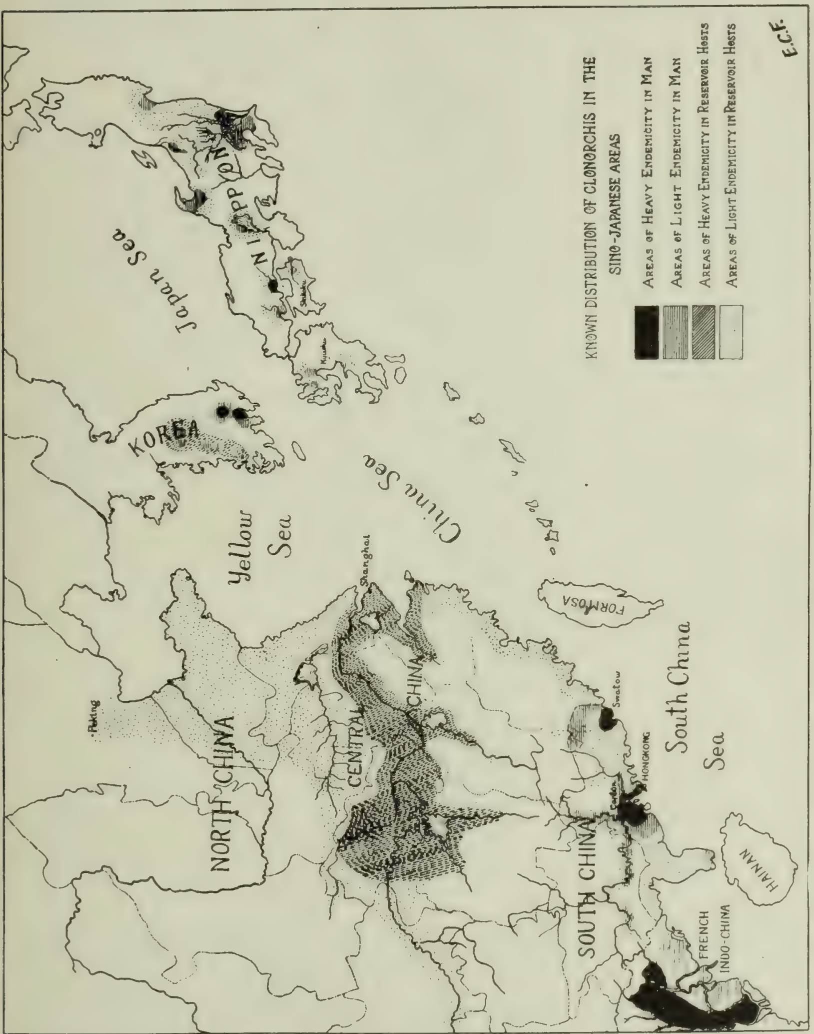


Fig. 101.—Map showing the distribution of *Clonorchis sinensis* in the endemic areas. (After Faust and Khaw, Am. Jour. of Hygiene.)

globose pharynx, posterior to which is the esophagus. This latter tube bifurcates into two somewhat inflated ceca, which continue posteriad to the caudal region of the body. The excretory bladder is a long sacculate structure, having a somewhat S-shaped course between the ovary and the posterior end of the body. The lateral

collecting tubules empty into the reservoir some distance behind the anterior extremity of the bladder. These collecting tubules proceed laterad, then anteriad, to the esophageal bifurcation, where they abruptly reflex and proceed again posteriad, with secondary branching along their course.

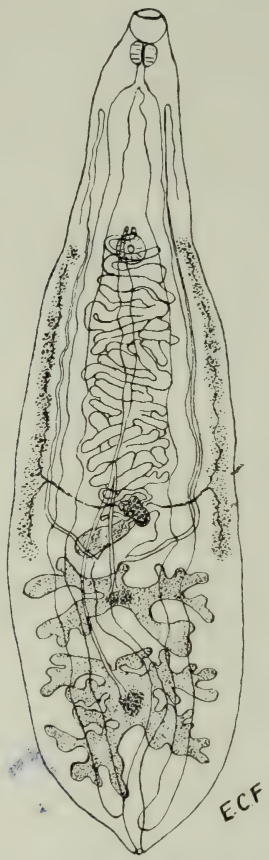


FIG. 102.—Adult specimen of *Clonorchis sinensis*, dorsal view. × 8. (Original.)

The testes are deeply branched organs lying one in front of the other in the posterior third of the body. From the central mass of each there arises a vas efferens, which proceeds to a region slightly in front of the ovary, before uniting with its mate to form the vas deferens. The latter soon enlarges into the vesicula seminalis, which ascends to the genital atrium immediately in front of the acetabulum. The ejaculatory duct is a weakly muscular extension of the seminal vesicle. Cirrus pouch, cirral organ and prostate glands are lacking. The small slightly lobed ovary lies in the mid-plane

just under the anterior tip of the excretory bladder. The retortiform receptaculum seminis lies to the left at an oblique angle. Between it and the ovary is the origin of Laurer's canal, which ascends to the dorsal surface where it opens through a minute pore. The vitellaria consist of minute follicles occupying the extra-cecal fields in the mid-third of the body. The transverse collecting ducts

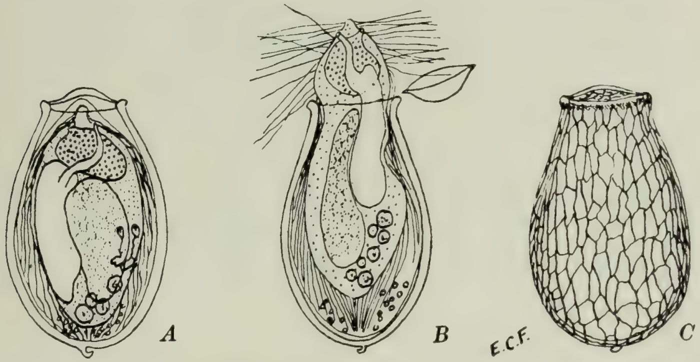


FIG. 103.—Egg of *Clonorchis sinensis*. *A*, egg with enclosed miracidium; *B*, miracidium escaping from shell under pressure; *C*, etching on surface of shell. × 1200. (From Faust and Khaw, Am. Jour. of Hygiene.)

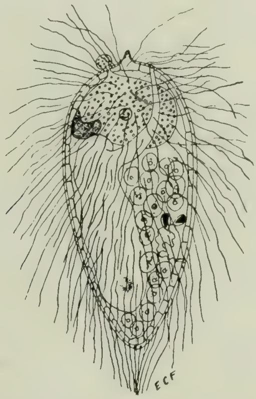


FIG. 104.—Miracidium of *Clonorchis sinensis*, showing internal organization, after artificial hatching. × 1800. (From Faust and Khaw, Am. Jour. of Hygiene.)

proceed mesad, uniting to form a common vitelline duct, which joins the oviduct and empties into the oötype. The shell glands which surround the oötype consist of minute aciniform cells, forming a loose tubular investment around the oötype. The uterus arises from the anterior right aspect of the oötype, proceeding as a closely coiled tubule through the inter-cecal space up to the genital atrium, where it terminates.

The Life Cycle of the Worm.—The eggs of *Clonorchis sinensis* (Fig. 103) vary from 27.3 to 35.1 μ in length by 11.7 to 19.5 μ in breadth; with an average of 29 by 16 μ. They are light yellowish-

FIG. 105.—First intermediate molluscan hosts of *Clonorchis sinensis*. *A*, *Parafossarulus striatulus;* *B*, *P. sinensis*, probably involved in the Central Yangtze Valley, China, but not yet incriminated; *C*, *Bithynia fuchsiana;* *D*, *B. longicornis*. × $1\frac{1}{3}$. (Original.)

brown in color and have the shape of an old-fashioned carbon-filament electric-light bulb. The operculum fits closely into the shouldered thickening of the shell like the lid of a sugar bowl. The egg when laid usually contains a mature miracidium (Fig. 104),

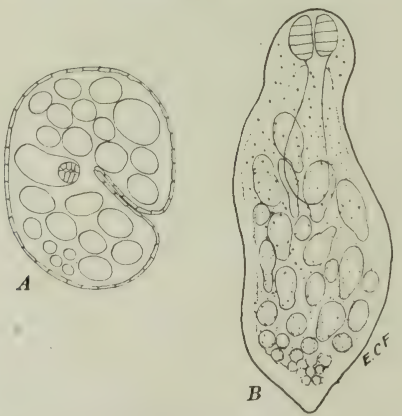


FIG. 106.—Parthenitæ of *Clonorchis sinensis*. *A*, sporocyst with developing rediæ, *B*, redia. (After Faust and Khaw, Am. Jour. of Hygiene.)

which, like that of *Opisthorchis felineus*, is characterized by an asymmetry of internal organs.

Hatching of *Clonorchis* ova does not take place normally outside

the body of the appropriate molluscan host. Viable eggs when passively ingested by certain species of bithyniid snails (*Parafossarulus striatulus, Bithynia fuchsiana* and *B. longicornis*, Fig. 105) hatch in the esophagus of the mollusc, the miracidium penetrating through the gut wall into the peri-esophageal lymph space, where it metamorphoses into a sporocyst (Fig. 106*A*), migrates toward the inter-hepatic lymph sinuses and there produces a progeny of rediæ (Fig. 106*B*). These latter, in turn, produce cercariæ with fluted lophocercous tails and pigmented eye-spots (Fig. 107). The mature cercariæ effect a rupture, first in the tissues of the rediæ, then in the taut outer tissue layers of the mollusc, escaping into the water, where they swim about vigorously. On coming within proximity of a fresh-water fish, the cercariæ attack the fish, penetrate under the scales and into the flesh, in the meantime discarding their caudal appendages. Thirty-four fresh-water fishes of the families Percidæ, Gobiidæ and Anabantidæ in China, Japan,

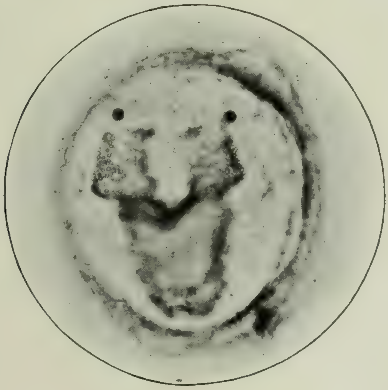


FIG. 108.—Cyst of *Clonorchis sinensis* from fresh-water fish. × 20. (After Faust and Khaw, Am. Jour. of Hygiene.)

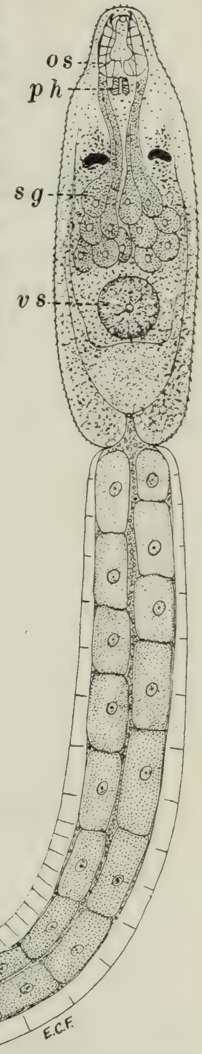


FIG. 107.—Cercaria of *Clonorchis sinensis*. × 240. (After Faust and Khaw, Am. Jour. of Hygiene.) *os*, oral sucker; *ph*, pharynx; *sg*, cephalic salivary glands; *vs*, ventral sucker.

Korea and Formosa have been found infected with *Clonorchis*. Once within the fish cystogenous fluid is slowly poured forth through the pores of the integument, "setting" in the form of a spherical or oval capsule. The presence of the cyst within the tissues of the fish provokes a reaction on the part of the host cells, resulting in

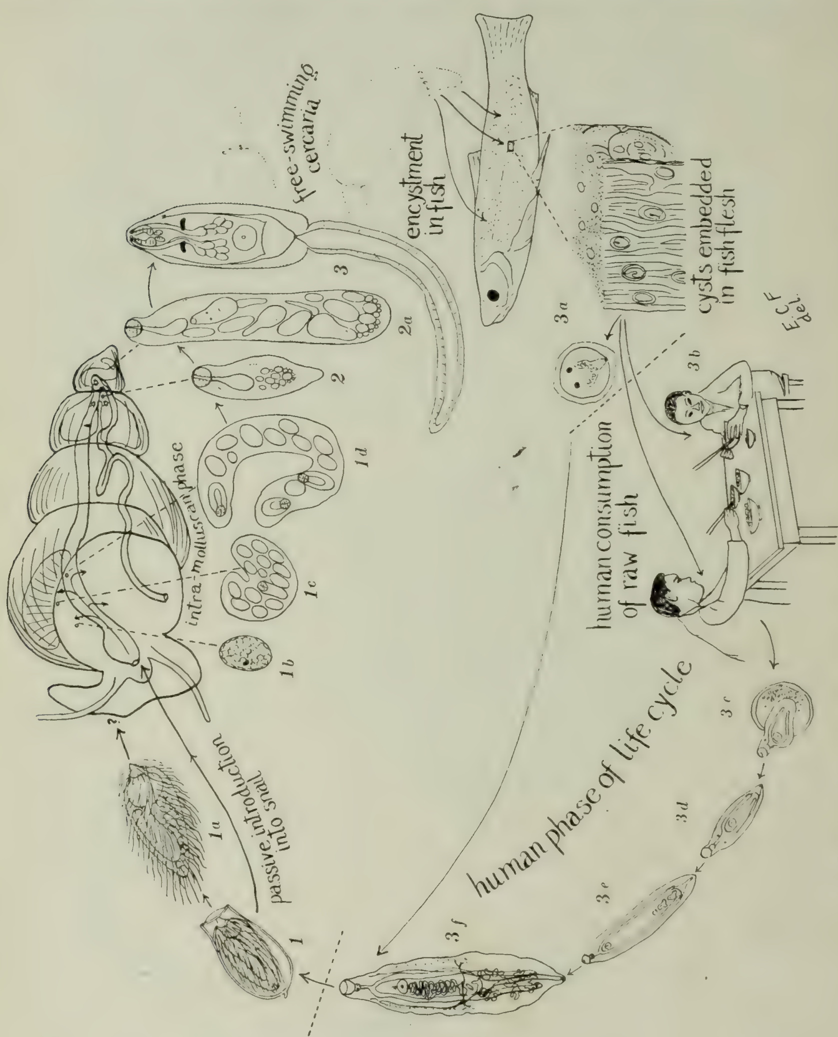


Fig. 109.—Diagram of the life cycle of *Clonorchis sinensis*. (Original.)

the deposition of an outer-tissue capsule around the true capsule (Fig. 108). Development of the encapsulated larva depends on the amount of nourishment in the immediate vicinity. On consumption of the infested raw fish the mammalian host becomes infected. In the stomach of the definitive host the cysts are digested

out of the flesh and the outer capsule is digested off. On passing into the duodenum the true cyst capsule is weakened so that the invigorated adolescaria breaks out, secures attachment to the duodenal wall, and migrates to the opening of the common duct. It continues its course to the biliary duct and wanders up to the distal biliary capillaries, where it settles down, sheds its integumentary spines and grows to adulthood.

The life cycle of *Clonorchis sinensis* is summarized in the accompanying diagram (Fig. 109).

Genus Pseudamphistomum Luehe, 1908.
(genus from ψευ, false, ἄμφω, double, and στομα, mouth).

18. **Pseudamphistomum truncatum** (Rudolphi, 1819) Luehe, 1908. This fluke, which may possibly be a parasite of man in Siberia, has been reported from the biliary passages of the seal, cat, dog, fox and glutton (*Gulo borealis*). It is recognized by the squarish pseudo-sucker-like posterior end of its body and, like other adult members of the subfamily **Metorchinæ**, by the possession of a spinose integument. The egg, measuring 29 by 11 μ, can hardly be differentiated from that of *Opisthorchis felineus*.

Pathogenicity and Symptomatology of Infections with Species of the Family Opisthorchidæ.—*Opisthorchis felineus*, *O. viverrini*, *O. noverca* and *Clonorchis sinensis*, which are all similar, in possessing flattened transparent ellipsoidal bodies with very poorly developed musculature, live in the distal capillaries of the biliary passages, where they cause the respective infections opisthorchiasis felinea, opisthorchiasis viverrini, opisthorchiasis noverca and clonorchiasis sinensis. They are more commonly present in the left liver lobe than in the right lobe, due to the fact that the path of migration into the former region is more direct than into the latter. Here these flukes may live for a period of five to twenty or more years. Except in very heavy infections the main portion of the liver tissue is relatively little modified. The changes induced by the parasites are essentially those recognized by Brumpt (1922, 1927) for *Fasciola hepatica*, namely, (1) destructive action, (2) mechanical effect, (3) irritative action and (4) toxemia.

The destructive action consists in desquamation of the biliary epithelium and the ingestion by the fluke of blood cells. Such cases are common but appear to have only slight effect on the general condition of the host. The blocking of biliary passages, resulting in biliary stasis, is relatively uncommon and seldom results in generalized icterus. In a series of several hundred animals experimentally infected with *Clonorchis sinensis* by the present author only three (two cats and one guinea-pig) showed evidences of

jaundice. The irritative action produced by these flukes consists of marked proliferation of the biliary epithelium, with crypt formation and multiple production of new biliary capillaries; periportal connective tissue hyperplasia; and fibrous tissue formation around "graves of eggs." There is, however, no true giant-cell tubercle around these eggs, as there is in schistosomiasis. There appears to be no marked generalized toxemia as in fascioliasis. Nevertheless, the changes in the walls of the biliary ducts occur in areas which worms are too large to reach, so that the determining factor in such instances may be the toxic secretions of the flukes. While bacterial invasion may play a secondary rôle in ulcerative processes developed in opisthorchid- or clonorchid-infections, the classical picture has been shown to be produced by these flukes in bacteria-free biliary passages. In heavy infections the pancreatic duct, as well as the biliary tract, is at times involved.

The lesions in animals infected with species of the family **Opisthorchidæ** are referable to three progressive stages. The lesions of the first degree consist primarily of proliferation of the biliary-tract epithelium, extensive infiltration of wandering cells and leukocytes around the portal spaces and interlobularly along the vessels, and the gradual thickening of the walls of the biliary passages through connective-tissue proliferation (Fig. 110*A*). In those of the second degree the walls become greatly thickened and the liver cells of adjacent zones are involved, due to the pressure of the growing connective tissue (Fig. 110*B*). In the lesions of the third-degree cirrhosis of the liver cells and destruction of the parenchyma are quite complete (Fig. 110*C*).

Cases of human infection with only a few worms probably never go beyond the first stage. In heavy infections (several hundred worms) the second type may be attained. Only in endemic areas of severe infestation where there is opportunity of continuous reinfection, is the advanced stage likely to be attained. Regions where such a degree of infection for clonorchiasis occur are the Okayama district in Japan, certain local areas in Kwangtung Province, China, and the Tonkin delta, French Indo-China. For opisthorchiasis felinea such districts are found in East Prussia and in the vicinity of Tomsk, Siberia. The data on the incidence of *O. viverrini* and of *O. noverca* are too inadequate to allow for definite statements regarding the severity of infection.

The only physician to have made an adequate investigation of the clinical symptomatology of an opisthorchoid infection is Inouye, who has studied *Clonorchis* cases in the Okayama endemic area, Japan. He recognizes (1) a mild type, without appreciable symptoms (correlated with the first-degree changes of the liver); a secondary stage, attended by diarrhea, edema, and hypertrophy of the liver (corresponding to second-degree lesions of the liver); and (3)

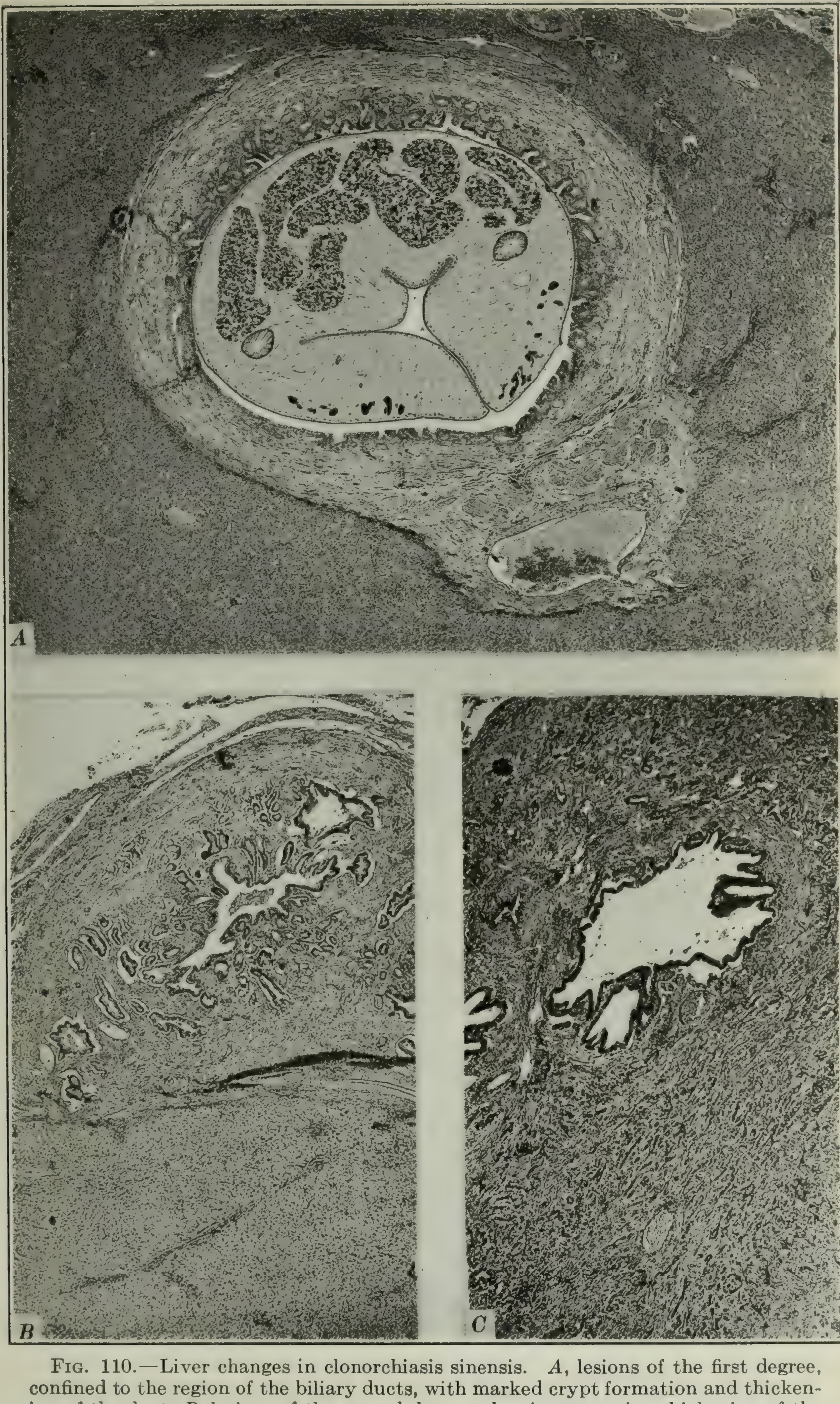


Fig. 110.—Liver changes in clonorchiasis sinensis. *A*, lesions of the first degree, confined to the region of the biliary ducts, with marked crypt formation and thickening of the duct; *B*, lesions of the second degree, showing extensive thickening of the biliary duct and fatty degeneration and vacuolization of the adjacent liver cells; *C*, third-degree lesions, a picture of advanced cirrhosis, consisting of destruction of the liver cells and obliteration of the bloodvessels. Enlarged. (Original.)

a severe type, with symptoms of the secondary stage, but aggravated by involvement of the hepatic portal circulation (due to hepatic cirrhosis). The common symptoms consists of irregularity of appetite, with a feeling of fullness and pressure after meals, and diarrhea. There is no significant modification of the blood picture. Mild cases usually go unnoticed unless diagnosed by the finding of the eggs in the stool. The more advanced cases must be differentiated from malignancies of the liver, hydatid cyst, beriberi, and from the usual types of hepatic cirrhosis.

Diagnosis.—This is based on the finding of eggs (Figs. 99, 103) of these flukes in the stool. The eggs require to be differentiated from those of heterophyid flukes.

Therapeusis.—Sodium antimony tartrate administered intravenously is helpful in reducing the number of worms in the biliary passages. The penta- and hexa-methyl rosanilins (gentian violet, crystal violet and methyl violet), administered orally in enteric-coated pills every other day, in doses not to exceed 30 mg. per dose, the total dosage not in excess of 300 mg. per kilo body weight, or intravenously in amounts of 40 cc., 0.5 of 1 per cent solution, every other day, until a total of not more than 6 grams of the dye has been given, will kill all of the worms which can be reached by the dye in helminthicidal amounts. In early cases this may result in complete cure; in chronic cases the number of worms may be reduced from one-half to nine-tenths. The amount of reduction in egg-production as an index of the number of worms present, may be determined by the egg-count method (Faust-Khaw modification of the Stoll technique, p. 530).

Prognosis.—In light infections clinical symptoms are frequently negligible. In heavier infections there is probably considerable loss of vitality and possibly a lowering of the bodily resistance to other diseases but such cases almost never die of fluke infection. In heavily infected cases death is frequently due to the parasites.

Prophylaxis.—These infections may be prevented by the thorough cooking of all fresh-water fish intended for consumption. In endemic areas the addition of ammonium sulphate to fresh night-soil is recommended as a sterilizing agent.

Superfamily Troglotrematoidea superf. nov.

This superfamily has been created for the family **Troglotrematidæ**, of which the parthenitic and marital stages are essentially unlike those of other trematode groups. Particularly unique are the egg and its enclosed larva, the microcercous cercaria and the excretory and genital systems of the adult worm (marita).

Type Family TROGLOTREMATIDÆ Odhner, 1914.

This family comprises a few species of distomes of which the relationship to other groups is relatively remote. The flukes are small to moderate-sized trematodes, ovate in contour, nearly circular in cross-section, with poorly developed musculature and well-developed genital organs. The only member of the family which concerns medical zoölogists is *Paragonimus westermani,* the maritæ of which usually encyst in the lungs but at times in other tissues of the body. Eggs of this species are operculate, broadly oval objects, with a yellowish-brown color. Melaniid snails serve as the first intermediate hosts and fresh-water crustaceans as the second intermediate hosts for this species. On consumption of the raw meat of such crustaceans containing the encysted adolescariæ, the definitive host becomes infected.

Genus Paragonimus Braun, 1899.

(genus from *παρά,* side-by-side, and *γόνιμος,* gonads).

19. **Paragonimus westermani** (Kerbert, 1878) Braun, 1899.

Synonyms.—*Distoma westermani* Kerbert, 1878. *D. ringeri* Cobbold, 1880. *D. pulmonum* Baelz, 1880. *D. pulmonis* Kiyona, 1881. *D. fusca* Baelz, 1881. *D. pulmonale* Baelz, 1883. *D. baelzi* Cobbold, 1884; *D. westermanni* Leuckart, 1889; *D. cerebrale* Yamagiwa, 1890; *Mesogonimus westermanii* Railliet, 1890; *Polysarcus westermanni* Lühe, 1899; (?) *Paragonimus kellicotti* Ward, 1908.

Historical.—*Paragonimus westermani,* the lung fluke, was discovered by Kerbert in 1878 in the lungs of two Bengal tigers which had died in the Hamburg and Amsterdam zoölogical gardens. In 1879 a Portugese resident of Formosa died of rupture of an aortic aneurysm and, on autopsy by Ringer, was found to have a parasite in his lungs, which was forwarded to Manson in Amoy and recognized by him as a distomate fluke. A year later Manson found large operculate ova in the rusty blood-flecked sputum of a Chinese patient who had lived in Northern Formosa. Finding these eggs to be similar to those expressed from Ringer's fluke, he sent the material to Cobbold, who pronounced it a new trematode and named it *Distoma ringeri* (1880). Meanwhile Baelz (1880) had found trematode eggs in the sputum of hemoptysic patients in Japan, and in 1883 recovered the worms from the lungs, naming them *Distoma pulmonale.* A few years later Yamagiwa and other Japanese investigators found the mature flukes in atypical foci of the body, including the brain, where their presence was accompanied by symptoms of Jacksonian epilepsy. The life cycle of *Paragonimus,* which involves melaniid snails and fresh-water crustaceans, has been elucidated by Nakagawa, Miyairi, Yoshida, Ando, Yokogawa and

Kobayashi. The definitive hosts other than man are the tiger, cat, wild cat, panther, fox, wolf, dog, pig, *Mustela melampus* and *Nyctereutes procyonides.* The distribution of the endemic foci is fairly extensive in the Far East, including Japan, Korea, Formosa, French Indo-China, Philippines, Siam, the Federated Malay, Bengal and Assam. Likewise the infection is recorded as endemic in New Guinea, Peru, Venezuela, Yucatan, Mexico and also in North America (if *Paragonimus kellicotti* be found to be identical with *P. westermani*). Although text-books usually include China in the endemic area no human case has ever been proved to have incurred the infection there.

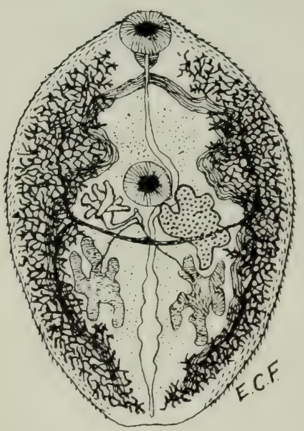


FIG. 111.—Adult specimen of *Paragonimus westermani*, ventral view. × 5. (Original adaptation from Leuckart, Parasiten des Menschen.)

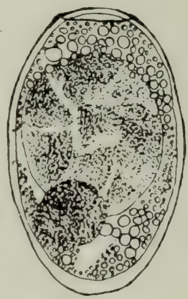


FIG. 112.—Egg of *Paragonimus westermani.* × 500. (After Yokogawa.)

Structure of the Adult Worm.—*Paragonimus westermani* (Fig. 111) is a plump, ovate fluke, abruptly rounded anteriorly and slightly more tapering posteriorly, measuring 7.5 to 12 mm. in length by 4 to 6 mm. in breadth by 3.5 to 5 mm. in thickness. Worms freshly obtained are reddish-brown; preserved specimens are gray. The integument is provided with scale-like spines, arranged in groups encircling the worm. These spines may be entire or toothed.

The acetabulum, which measures 0.8 mm. in cross-section, is situated in the mid-plane somewhat in front of the middle of the body. The oral sucker, with a diameter of 0.75 mm., is subterminal. It leads into a globose pharynx (0.3 mm. in trans-section), followed by a short esophagus, which bifurcates to form the somewhat meandering ceca, the latter extending to the subcaudal region of the body. The excretory pore is slightly ventral in position. The bladder is a long convoluted pouch reaching from the posterior

extremity anteriad to the plane of the pharynx. The lateral collecting tubules arise from the bladder somewhat behind the ovary, proceed laterad and branch into anterior and posterior stems, each with numerous secondary and tertiary twigs.

The testes, which are irregularly lobed organs, are situated slightly obliquely in the posterior third of the body. From the center of each testis there arises a vas efferens. The two vasa run antero-mesad and in the vicinity of the oötype unite into the vas deferens. The latter is a broad tube lying obliquely in a dorso-ventral position and constitutes the vesicula seminalis. At its outer extremity it is modified into the pars prostatica, followed by the ejaculatory duct. As the ejaculatory duct approaches the ventral surface it unites with the metraterm, to empty through a common opening into the genital atrium. A cirrus pouch is lacking. The genital pore lies behind the acetabulum and slightly to the right of the mid-line. The ovary is a lobed organ, slightly larger than the testes, and is situated behind and somewhat to the left of the acetabulum. From its posterior aspects there arises an oviduct which proceeds dorsad and enters the mass of the shell glands. *En route* the oviduct has an out-pocketing, consisting of a small receptaculum seminis, with a delicate convoluted tubule (Laurer's canal), which opens on the dorsal surface of the worm. The oviduct also receives the common vitelline ducts, the latter having connection through lateral ducts with the extensive vitelline follicles situated in the lateral fields and extending from the region of the pharynx to the posterior end of the worm. On piercing the shell glands the common female duct becomes transformed into the oötype, which has a general dorso-ventral position. The uterus arises from the ventral end of the oötype, proceeds across to the right side of the body and in the region postero-dextral to the acetabulum is knotted into several coils, finally emerging on the inner side as the metraterm and uniting with the ejaculatory duct to enter the genital atrium.

The Life Cycle of the Worm.—The eggs of *Paragonimus* (Fig. 112) are broadly oval objects with a distinct operculum at one end inserted into a slightly thickened collar region, and with a thickening of the shell at the abopercular end. They are golden-brown in color and measure from 80 to 118 μ in length by 48 to 60 μ in cross-section. The freshly laid egg is immature and contains an abundance of heavy yolk cells. The eggs are voided into the cystic pockets around the worms, and on rupture of these pockets the eggs escape. They are most commonly recovered from the sputum, which has a characteristic rusty-brown tinge when they are present. In about 40 per cent of the cases they are also found in the feces. The eggs require from four to seven weeks for complete development, whereupon they hatch and the miracidia, escaping into the water, swim about in a vigorous fashion. Upon coming in contact

with the appropriate melaniid snail, according to Japanese investigators, they attack and penetrate its soft tissues. *Melania libertina* (Fig. 113) is said to be the optimum molluscan host. Other melaniid snails which are believed to have been incriminated in the Orient are *M. ebenina, M. hidatchiens, M. multicincta, M. nodiperda, M. obliquegranosa, M. paucicincta,* and (?) *Melanoides tuberculatus. Ampullaria luteostoma* is said to be involved in Venezuela, but this requires verification, since this mollusc is only distantly related to the optimum hosts in endemic areas in the Far East.

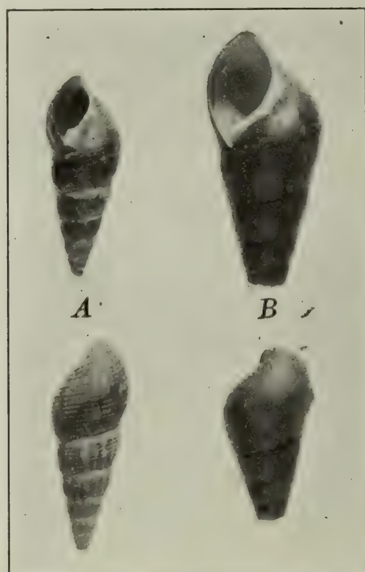


FIG. 113.—First intermediate hosts of *Paragonimus westermani*. *A*, *Melania libertina; B*, *M. ebenina.* Natural size. (Original photographs.)

On entering the mollusc the miracidia cast off their ciliated epithelium, become transformed into globular or ellipsoidal sporocysts and produce the first generation rediæ. These rediæ escape from the mother sporocysts, wander farther up the lymph spaces of the mollusc and, after reaching the inter-hepatic lymph sinuses, produce a second generation of rediæ (Fig. 114). These, in turn, produce the cercariæ. These larvæ (Fig. 115) are microcercous forms, with an ellipsoidal body and a short knob-like caudal appendage. They measure from 200 to 220 μ in length by 70 to 80 μ in breadth. The integument is covered with minute delicate spines, which are seldom seen in preserved material. The acetabulum is relatively small and the oral sucker disproportionately large. Inserted in the dorsal wall of the oral sucker is a simple cone-shaped stylet. The bladder is oval, has

a thick wall and opens subterminally. There are two types of cephalic glands opening at the sides of the stylet and, in addition,

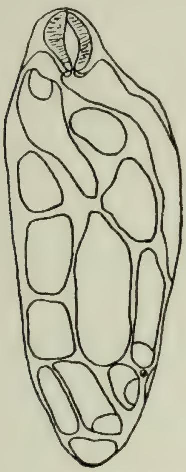


FIG. 114.—Second generation redia of *Paragonimus westermani*, from the molluscan host. × 100. (After Kobayashi.)

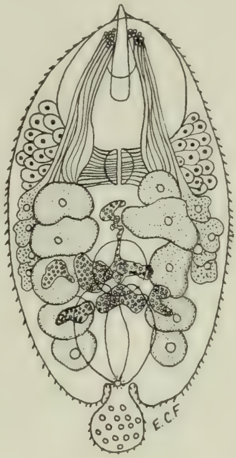


FIG. 115. — Cercaria of *Paragonimus westermani*. × 500. (Original.)

larger groups of pharyngeal glands. The genital primordia, which are situated in the middle of the body, are well developed. Several

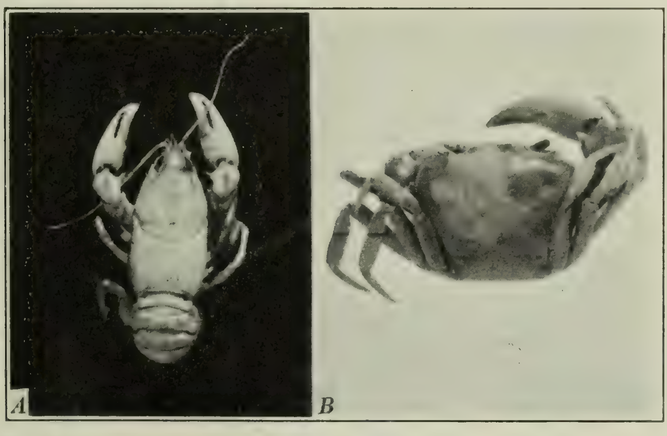


FIG. 116.—Second intermediate hosts of *Paragonimus westermani*. *A*, *Astacus japonicus*; *B*, *Potamon dehaani*. Natural size. (Original photographs.)

weeks are required for completion of the molluscan phase of the life cycle.

On erupting from the molluscan host the cercariæ of *Paragonimus*

swim around in the water and, in the event a crayfish or appropriate crab is in the immediate vicinity, swarm around these crustaceans and penetrate their soft parts, where they secrete cystogenous fluid and encyst. The following species of crayfish and crabs have been found infected in the Sino-Japanese areas: *Astacus japonicus* (Fig. 116*A*), *A. similis, Eliocheir japonicus, E. sinensis, Potamon dehaani* (Fig. 116*B*), *P. obtusipes, Parathelphusa sinensis, Sesarma dehaani. Pseudothelphusia iturbei* has been incriminated in Venezuela. The cysts (Fig. 117) are spherical pearly-white objects found in practically all the soft parts of the crustacean host, but can be most readily detected in the gill filaments.[1] They lie encapsulated in an outer host tissue envelope. They are apparently able to increase in size, depending on the abundance of food supply with which they are surrounded. The definitive host is infected from eating raw the soft parts of fresh-water crabs or crayfishes infested with the cysts, and, to a lesser extent, perhaps, by the ingestion in drinking water of cysts that have become free from their crustacean host.

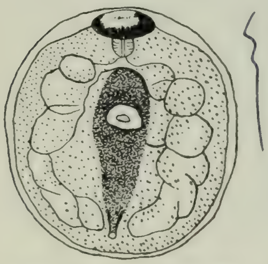


Fig. 117. — Encysted adolescaria of *Paragonimus westermani* from the fresh-water crab, *Potamon dehaani*. × 500. (After Yokogawa.)

On entering the stomach of the mammal, the cyst is digested out of the surrounding tissue and the outer (false) tissue capsule is then digested off. Upon arrival in the duodenum the true cyst capsule is weakened so that the adolescaria emerges, whereupon, according to the investigations of Yokogawa, it penetrates through the wall of the small intestine, traverses the abdominal cavity, whence it migrates upward through the diaphragm to the thoracic cavity, penetrates through the pleura into the lungs and finally arrives in the bronchioles, where it settles down and become pocketed off by a cystic wall resulting from the infiltration of host tissue cells. Here the worm grows to adulthood.

Localization of the flukes in the lungs is apparently the most usual outcome of the migration of the adolescariæ, although it is not necessarily obligatory, since the worms are at times found in foci far removed from the respiratory tract, such as the various lymph spaces in the body, the ventricles of the brain, the orbit, and muscles of the extremities. The period of migration and development within the definitive host usually occupies several weeks.

Pathogenicity and Symptomatology.—This fluke, which causes paragonimiasis westermani, is normally a resident of the lungs. The adolescaria arrives in the intestine of the host in the encysted

[1] Cysts of *Paragonimus* must not be confused with other species of encysted flukes commonly found in the liver of crustaceans.

condition along with infested raw fresh-water crab or crayfish flesh. According to the researches of Yokogawa, the route of migration of the excysted larva is a devious one, first passing through the intestinal wall, then traversing the abdominal cavity, penetrating through the diaphragm into the pleural cavity, entering the lungs and, on arriving in a bronchiole, settling down and developing to adulthood. Frequently, perhaps in the majority of cases of experimental hosts, the parasites are found in pairs, but in man they usually develop singly. The presence of these flukes in the lungs provokes a tissue reaction on the part of the host (Fig. 118), consisting of a leukocytic infiltration immediately around the parasite and the development of layers of fibrous tissue around the latter, thus constituting a thick cyst wall around the invader, and more or less effectively excluding the by-products of the latter from the body of the host. These cysts, which may be superficial but are more commonly formed throughout the deeper tissues of the organ, are usually the size of a filbert. Between the cyst wall and the fluke there is an accumulation of blood-tinged purulent fluid with minute rusty-brown flecks, which are clusters of the eggs of the parasite. Although the lungs are perhaps the most favorable location, the fluke is at times more generalized in its distribution in the body, being found in the liver, intestinal wall, mesenteric glands, muscles, testes, brain, or attached to the peritoneum or pleura, where it may be recognized by the peculiar slaty-blue color of the cyst. In the lungs the cystic pockets housing the worms, if not actually in the bronchi, are usually connected by channels with the respiratory passages and thus discharge their eggs and by-products from time to time into the air passages. Cysts in the lungs not opening into the bronchi, as well as those in other tissues of the body, may work their way to a mucous or epithelial surface, such as the intestinal mucosa, biliary tract epithelium, pleural or peritoneal surface or even the skin, in which foci they may proceed to ulcerate. Musgrave, who made a careful study of paragonimiasis lesions, recognizes four types, namely, (1) the non-suppurative lesion, (2) the tubercle-like lesion, (3) the suppurative lesion, and (4) the ulcerative lesion. The first type consists in the infiltration of the tissue (Fig. 118) by eggs of the fluke, at first provoking no tissue reaction but later producing round-cell or connective-tissue infiltration, eventually leading to abscess-formation and possibly ulceration. The eggs or parasites on serous surfaces may give rise to adhesive inflammation. In most instances the host tissue attempts to delimit the process by a fibrous wall, thus producing the typical paragonimiasis lesion, with the parasite and its discharged products in the center, surrounded by a thick fibrous wall and superficially an area of connective tissue. The abscess may at times form caseous material, with a tubercle-like aspect. In the ulcerative type

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healing may be attempted but is only partly successful. The infiltration of the eggs into the tissues produces a peppered rusty-brown appearance, which is frequently visible to the naked eye.

FIG. 118.—Section of lung with *Paragonimus* infection, showing leukocytic infiltration, fibrous connective-tissue encapsulation and eggs of the parasite throughout the alveoli. (Original, from experimental material presented to the author by Professor S. Yokogawa.)

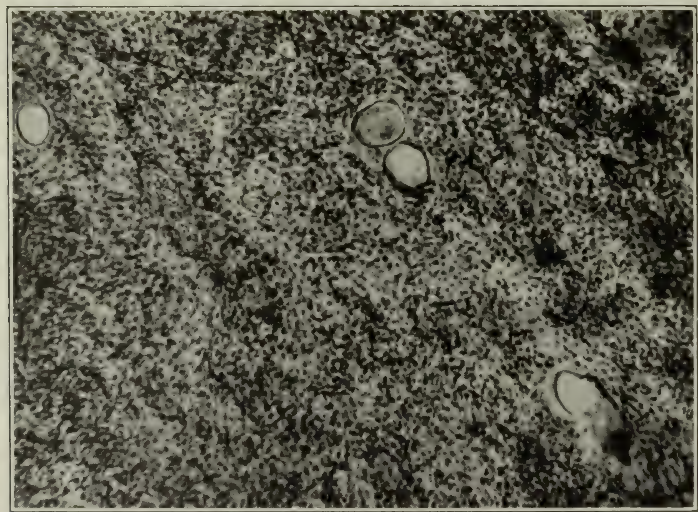

FIG. 119.—Section of abdominal tumor infiltrated with *Paragonimus* eggs. (Original from a preparation by Dr. A. I. Ludlow.)

The paragonimiasis lesions in the lungs consist in generalized or localized diffuse cirrhosis, cystic dilatation of the bronchi, pseudopneumonia, and tubercle-like abscesses, and are usually accompanied by cough and hemoptysic discharge containing eggs, from which characteristic the disease has been commonly designated as "endemic hemoptysis." The physical signs in this type of the disease may suggest bronchopneumonia or pleural effusion. The abdominal type, in which the lesions may be in the liver, spleen, pancreas, intestines, or on the serous layers, usually produces much vaguer symptoms. In the intestinal variety diarrhea frequently occurs, with eggs in the feces. If the parasites become localized in the various glands of the body (Fig. 119) particularly those of the groin and the prostate, inflammation in such foci may give rise to febrile reaction. The cerebral type is accompanied by a peculiar variety of Jacksonian epilepsy, with eventual symptoms of hemiplegia, monoplegia, aphasia, ocular dysfunction, or paresis. There is usually a localized eosinophilia around the paragonimiasis abscesses. In case the toxic products of the worm become absorbed by the body, generalized eosinophilia may result. Under such conditions complement-fixation is positive and may be used for diagnostic purposes where other methods are not feasible. Human infection is confined to the Far East, with certain heavy endemic foci in Japan, Southern Korea and Formosa.

Diagnosis.—This depends on the finding of *Paragonimus* eggs in the body excreta or discharged from cutaneous lesions. In the pulmonary type eggs can usually be recovered from the sputum, which is tinged a rusty-brown by their presence. Likewise these eggs occur in the feces of about 40 per cent of patients having only pulmonary symptoms. In the intestinal type with diarrhea the eggs are usually discharged directly into the intestinal lumen. In other foci of the body diagnosis of the parasite may require postponement until biopsy can be performed and a section of the tissue examined microscopically. The pulmonary type needs to be differentiated from bronchopneumonia, tuberculosis, bronchospirochetosis and pleural effusion. The intestinal type requires differentiation from the intestinal schistosomiases. The diffuse abdominal type is perhaps the most difficult to diagnose. The cerebral type must not be confused with idiopathic Jacksonian epilepsy or brain symptoms due to cysticercosis cellulosæ or hydatid disease. A history of the patient having resided in endemic areas frequently aids in diagnosis.

Therapeusis.—Cases treated with emetin or tartar emetic are temporarily relieved of pulmonary symptoms. Cures following administration of these drugs are doubtful. Wherever feasible, removal of the patient from endemic areas is recommended. After five or six years such individuals frequently recover from clinical symptoms.

Prognosis.—Fair, except in heavy infections or in individuals where the parasite is localized in primary centers such as the brain.

Prophylaxis.—The disease may be prevented by abstinence from eating raw fresh-water crab or crayfish meat.

Superfamily Hemiuroidea nom. nov. pro Hemiurida Dollfus, 1923.

This superfamily contains those species of distomate flukes with a Y-shaped excretory bladder, which have cystophorous cercariæ. These cercariæ gain entrance to the copepod second intermediate host, where they live unencysted in the body cavity of that host. The maritæ are normally parasitic in lower vertebrates.

Family ISOPARORCHIDÆ Poche, 1926.

Genus Isoparorchis Southwell, 1914.

(genus from ἴσος, equal, παρά, side-by-side, and ὄρχις, testis).

20. **Isoparorchis trisimilitubis** Southwell, 1914.

Synonym.—*Leptolecithum eurytremum* Kobayashi, 1921(?).

This species of fluke, belonging to the family **Isoparorchidæ**, is a common parasite of the air bladder of fishes in India and the Far East, particularly the catfishes and the eels in Japan and Central China. Chandler has identified it from the intestine of a human case in Eastern Bengal, where seven specimens of the worm had been expelled after thymol treatment. There is evidence of a second case of human infection with this species from Hunan Province, China. In both instances infection was probably accidental, brought about, no doubt, through the consumption of raw infected fishes. In this respect the infection resembles pharyngeal fascioliasis.

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CHAPTER XV.

THE CESTODES OR TAPEWORMS. STRUCTURE AND LIFE HISTORY.

GENERAL DESCRIPTION.

The cestodes or tapeworms are Platyhelminthes which, with the exception of the ciliated embryo of the Order Pseudophyllidea, are parasites during their entire life. Their name, derived from the Greek word κεστος, which literally means "girdle" and has more popularly been translated "tape," indicates that they are elongated ribbon-like organisms. With the exception of a few types (as, for example, *Cylindrotænia*) they are flattened dorso-ventrally. They all possess an antero-posterior polarity. The region usually considered to be the anterior end, and popularly called "the head," is provided with structures for attachment of the worm to the tissues of the host (Fig. 120). It possesses suctorial pockets (*Tænia, Dipylidium*), or grooves (*Diphyllobothrium*), and frequently has hooklets. More technically speaking this entire region of attachment is referred to as the *scolex*. The anterior protrusion from the more fleshy part of the scolex, around or on which the hooklets are arranged, is called the *rostellum*. Behind the scolex is the region commonly designated as the "neck." In the primitive group of cestodes, the **Cestodaria**, the entire region posterior to the "neck" consists of a single segment, but in the more fully evolved species (**Cestoda** *sensu stricto*) the segments or *proglottids* are multiple (Fig. 121). These proglottids originate from the posterior portion of the neck, which is the *region of growth*. Although various stages of maturity follow one another *ad seriatim* almost imperceptibly, three stages are recognizable in the development of the proglottids. Those immediately behind the region of growth are the *immature proglottids, i. e.*, their sexual organs have not yet become differentiated. Behind this first series is one consisting of *mature proglottids*, or those in which the sexual organs are completely formed. Succeeding this series distally is a terminal group of *gravid proglottids*, in which the eggs have already been developed and the reproductive organs have more or less been crowded out or replaced by the uterus with its large complement of eggs. In its simplest form the segmented cestode has at any one time only one immature, one mature and one gravid proglottid (*Echinococcus granulosus*, Fig. 170). In

most species, however, there are from a few to many proglottids belonging to each stage. The size and number of these proglottids determines the size and length of the tapeworm. Thus certain species are at most only a few millimeters long while others may reach several meters in length. When the proglottids become gravid

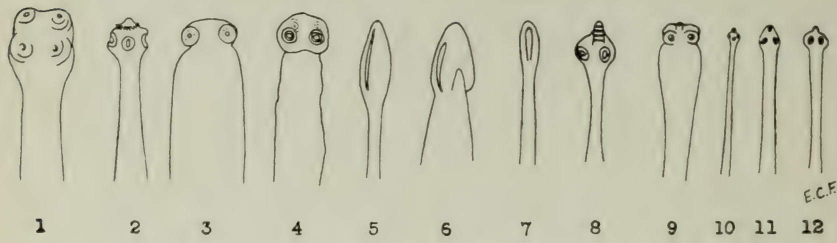


FIG. 120.—Anterior ends of human tapeworms. 1, *Tænia saginata;* 2, *T. solium;* 3, *T. africana;* 4, *T. confusa;* 5, *Diphyllobothrium latum;* 6, *D. cordatum;* 7, *D. mansoni;* 8, *Dipylidium caninum;* 9, *Davainea madagascariensis;* 10, *Hymenolepis nana;* 11, *H. diminuta;* 12, *Bertiella satyri.* × 6. (Original.)

and the eggs are ripe such segments either break off or disintegrate *in situ*, thus providing that the elongation of the worm does not continue indefinitely.

The attachment end of the tapeworm serves only as a holdfast organ and never as a *via media* of nourishment. The adult organism

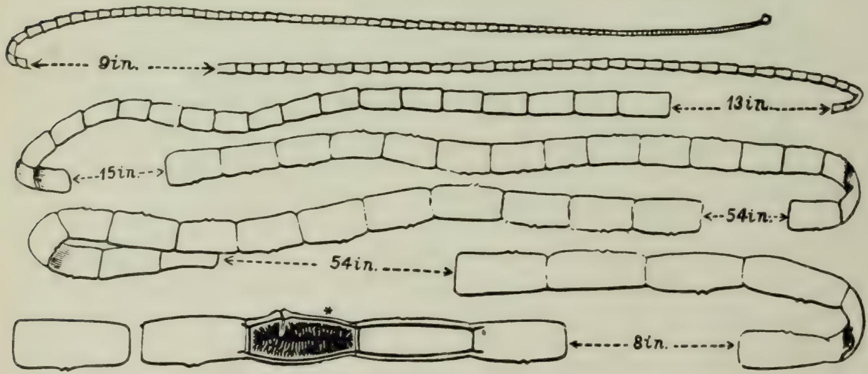


FIG. 121.—*Tænia saginata*, complete worm, showing scolex, neck, immature, mature and gravid proglottids; indicates gravid segment. Natural size. (From Leuckart, Parasiten des Menschen.)

lies in the mid-gut of its host, usually with the "head" end most proximal and the gravid proglottids most distal in position. In this medium of digested or semi-digested food, the worm has an abundant supply of nourishment always at hand. There are no special organs of digestion or absorption, food being taken in through

the entire surface of the body and being immediately transformed into parasite tissue or storage products. Thus growth (*i. e.*, production of new segments) is the immediate result of the absorption of predigested food supplied by the host.

Coördination of the entire ribbon of segments in the tapeworm's body is imperfect. This is due to the relatively poor development of the nervous system in all parts of the body except in the scolex, where there is a rather complicated set of ganglia and connecting commissures, as well as apical nerves which are both sensory and motor in function (Fig. 122). Arising from the "central nervous system" of the scolex and proceeding through the complete series of proglottids are the longitudinal nerve trunks. These usually consist of one main lateral nerve and a pair of accessory nerves on each side of the proglottid. In addition, there are two pairs of submedian nerve fibers, making a total of ten longitudinal nerves, the whole being connected at the posterior border of each proglottid by an annular commissure.

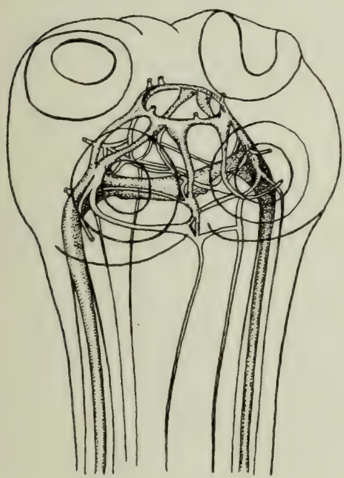
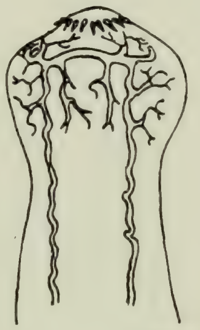


Fig. 122.—Schematic diagram of the nervous system of *Tænia*, adapted from various authors.



E.C.F.

Fig. 123.—Head of *Tænia* showing excretory vessels. (After Leuckart, Parasiten des Menschen.)

The excretory system is primitively like that of the trematodes, with flame-cell termini, capillaries and collecting tubules, the latter emptying into longitudinal trunks. Typically each side of the body has both a dorsal and a ventral longitudinal trunk with anterior anastomoses and with a terminal bladder; but in many species, particularly in the adult stage, this has become simplified so that only one pair of lateral trunks is visible, arising from a complex network in the head (Fig. 123) and having a transverse anastomosis

at the posterior margin of each proglottid. Likewise, since the terminal bladder is lost with the separation of the distal most segment from the remainder of the worm, the lateral trunks discharge separately from the most distal proglottid still attached to the worm.

The main function of the cestode is egg production. To this end all other functions and structures are subservient. Not only is each worm self-sufficient as far as its sexual products are concerned, but each proglottid is also independent of every other with respect to egg-production. Each proglottid contains both male and female reproductive organs. In a few instances (*Dipylidium*, *Diplogonoporus*) each proglottid is provided with a double set of such organs.

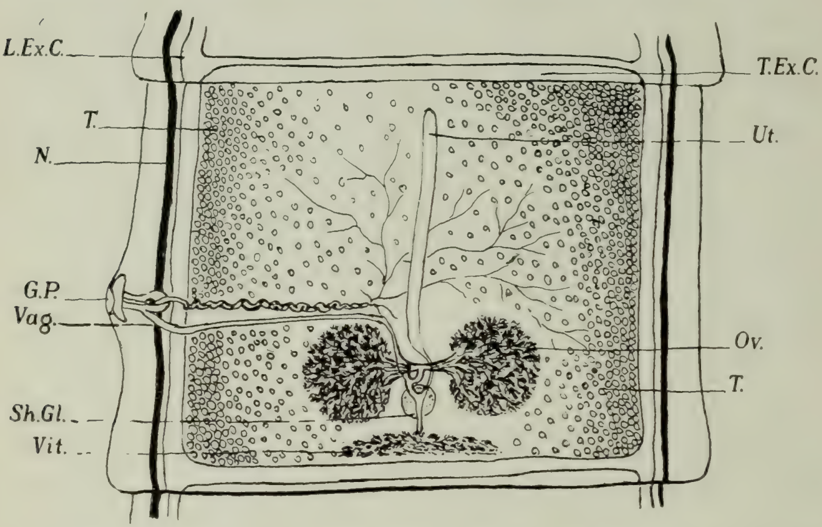


FIG. 124.—Proglottid of *Tænia saginata* (Goeze) showing genitalia. *L.Ex.C.*, left excretory canal; *T.Ex.C.*, transverse excretory canal; *Ut.*, uterus; *T.*, testis; *N.*, nerve; *G.P.*, genital pore; *Vag.*, vagina; *Ov.*, ovary; *Sh. Gl.*, shell gland; *Vit.*, vitellarium. × 10. (From Leuckart in Fantham, Stephens and Theobold, *Animal Parasites of Man.*)

While cross-fertilization from one worm to another in close apposition and from one proglottid to another of the same worm is not an infrequent occurrence, it is usual for each proglottid to be self-fertilized.

The male reproductive organs consist of both primary and secondary structures (Fig. 124). The follicular *testes*, which are commonly multiple, are distributed throughout the median plane of each proglottid. *Vasa efferentia* from the testes join one another in dendritic fashion to form the *vas deferens*, a coiled or convoluted tubule which proceeds from the middle region of the worm toward the lateral margin or ventrad, there to open into the genital atrium.

In its outermost portion it may become differentiated into *prostate* and *cirral organs,* the two being enclosed in a *cirrus sac.* Between the vasa efferentia and the vas deferens there may be a storage reservoir or *seminal vesicle.* The female reproductive organs likewise consist of primary and secondary structures. From the genital atrium a more or less tubular *vagina* proceeds toward the oötype, the latter structure being situated in a median posterior position in each proglottid. The inner end of the vagina is frequently differentiated into a reservoir, or *seminal receptacle,* followed by a constricted tubule, the *spermatic duct.* The ovary (Figs. 124 and 125), a bilobed multiglandular structure (except in *Dipylidium,* where there is a single ovarian mass for each set of reproductive

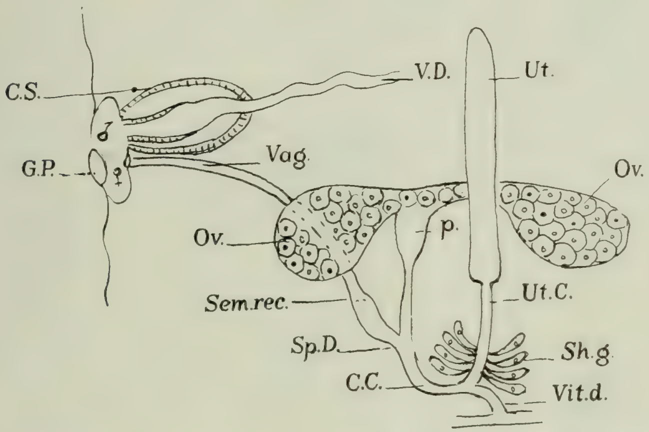


FIG. 125.—Diagram of genitalia of a cestode. *G.P.*, genital pore; ♀ ♂, male and female ducts opening into genital sinus; *C.S.*, cirrus sac; *V.D.*, coiled vas deferens ("outer seminal vesicle"); *Vag.*, vagina; *Sem. rec.*, seminal receptacle; *Sp.D.*, spermatic duct; *C.C.*, fertilization canal; *Vit.d.*, vitelline duct; *Sh.g.*, shell gland; *Ut.C.*, uterine canal; *Ut.*, uterus; *Ov.*, ovary; *p.*, pumping organ. (From Fantham, Stephens and Theobald, *Animal Parasites of Man.*)

organs), is situated posterior to the mid-plane of the body. It is connected with the oötype by the *oviduct,* which receives the spermatic duct along its course. The *vitellaria,* which may either consist of a bilobed mass (*Tœnia* species) or a single mass (*Dipylidium*) posterior to the ovary, or of many discrete follicles distributed throughout the mesenchyma of the segment (*Diphyllobothrium*), discharge their products into ducts which unite to enter the oötype as a common *vitelline duct.* Surrounding the oötype is a cluster of unicellular "*shell glands.*" Arising from the anterior aspect of the oötype is the *uterus,* which may open through a uterine pore (*Diphyllobothrium*) or may end blindly (*Tœnia*). In the former case the uterus becomes more and more tightly coiled as it elongates to accommo-

date the eggs which are forced into it from the oötype (Fig. 126, *9, 10, 11, 12*). In the latter case the blind pouch develops lateral arms to accommodate the eggs (Fig. 126, *1–4*). In the most immature proglottids the reproductive organs cannot be discerned. They

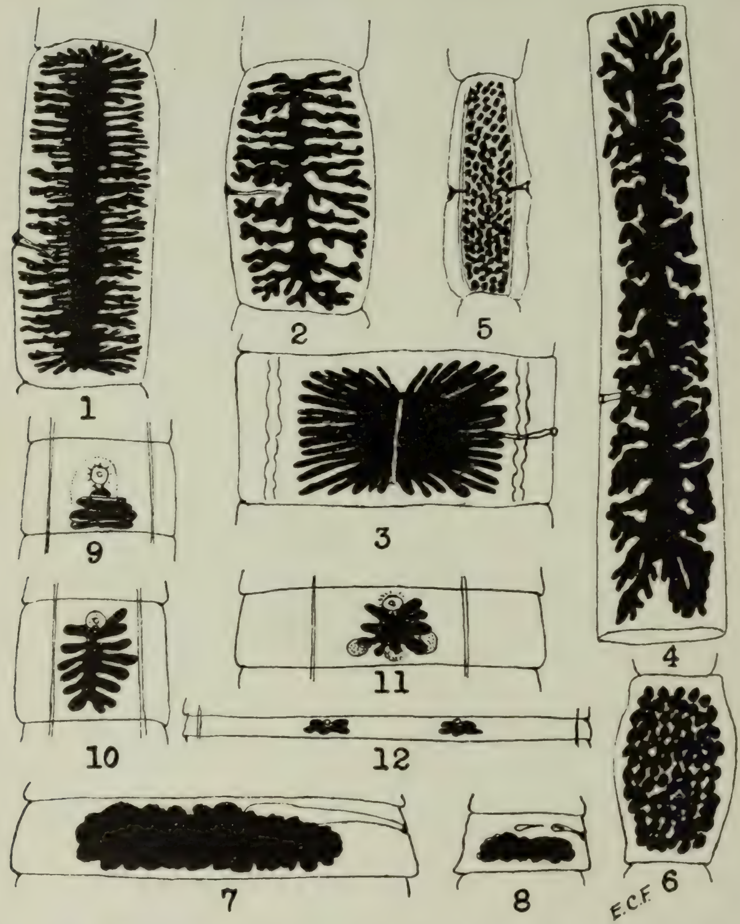


FIG. 126.—Gravid proglottids of the important human tapeworms. 1, *Tænia saginata;* 2, *T. solium;* 3, *T. africana;* 4, *T. confusa;* 5, *Dipylidium caninum;* 6, *Davainea madagascariensis;* 7, *Hymenolepis diminuta;* 8, *H. nana;* 9, *Diphyllobothrium mansoni;* 10, *D. cordatum;* 11, *D. latum;* 12, *Diplogonoporus grandis.* 1–5 and 9–12, × 3; 6–8, × 15. (Compiled and adapted from various sources.)

become more and more distinct as the proglottid matures and are most readily studied just as egg-making begins. With the production of a large number of eggs, the need for storage of the ripe sexual products takes precedence over egg production and the sexual organs, at least in the higher groups of the cestodes (the Cyclophyllidea),

all gradually atrophy, with the exception of the uterus, which becomes greatly distended and tends to fill the entire proglottid. The shape of the gravid uterus (Fig. 126, *1–12*) is frequently of diagnostic value in determining the species of tapeworm.

The egg is assembled in the oötype. It consists of the fertilized ovarian cell and an aggregation of yolk cells, the whole being surrounded by an egg-shell. In the **Pseudophyllidea** (*i. e., Diphyllobothrium,* Fig. 130, *Diplogonoporus,* Fig. 143) which possess a uterine pore, the egg is oval in contour like that of a trematode, and is provided with an operculum. In the more highly developed groups, such as the **Cyclophyllidea** (*i. e., Tænia,* Fig. 163 *a, b; Dipylidium,* Fig. 149 *c, d; Hymenolepis,* Figs. 151 *c,* 153 *c*), where the uterus is a blind pouch, the naked egg cell is frequently surrounded not only by an egg-shell but also by additional embryonic membranes. In most species these outer membranes surround each egg individually; in the case of *Dipylidium* (Fig. 149 *c*) one uterine or embryonic membrane envelopes a group of several eggs. None of these higher groups has operculate eggs. In the **Pseudophyllidea** the eggs escape from the uterus while they are still undeveloped and development of the embryo occurs in the free state; in the higher groups the embryo is mature when the egg is set free from the uterus.

THE LIFE CYCLE OF CESTODES.

The embryo is already fully developed and ready to hatch upon its escape from the uterus of the parent worm. In the case of the **Pseudophyllidea** the eggs are discharged through the uterine pore. In cyclophyllidean species escape is effected through rupture of the uterus. The larva within the egg is designated as the *onchosphere* (*ονκος,* hook, *σφαίρα,* ball), or, because of the fact that it possesses three pairs of hooklets, is called the *hexacanth* (ἕξ, six, ἄκανθα, spine) embryo. In the **Pseudophyllidea** the mature embryo is provided with a ciliated epithelium. The egg hatches in a moist medium and the emergent larva swims about in the water. All other cestode eggs are non-ciliated, and hatch only after being ingested by their intermediate host.

With the exception of *Hymenolepis nana,* all of the known human tapeworms require two or more hosts, a *definitive host* for the *marital stage* of the worm, and one or more *intermediate hosts* for the larval stage. In the case of *Hymenolepis nana* the appropriate host (man, rat, mouse) serves both as intermediate and definitive host. The onchosphere gains passive access to the intestinal tract of the intermediate host, whereupon it actively works its way into the intestinal wall (*Hymenolepis nana*), or through the intestinal wall into the lymph channels (*Tænia* species) or into the body cavity of this host (*Diphyllobothrium, Dipylidium*), in which place it becomes

metamorphosed into a larva, which eventually comes to possess a scolex similar to that of the adult worm. In its earliest stage of transformation, while the metamorphosis is still incomplete it is

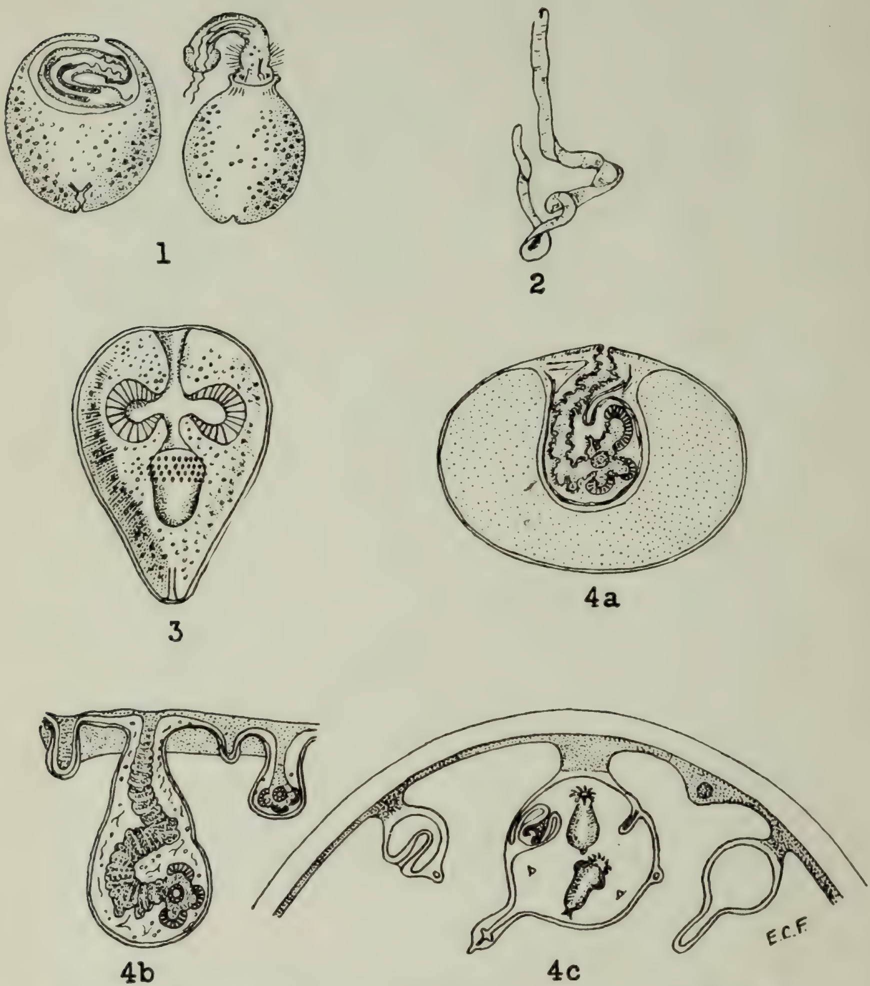


FIG. 127.—Types of larval stages of tapeworms. 1, plerocercus (of *Tetrarhynchus*) from a Mediterranean perch (after Leuckart, Parasiten des Menschen); 2, plerocercoid (sparganum) from man, (original); 3, cysticercoid of *Dipylidium caninum* (after Leuckart, Parasiten des Menschen); 4*a*, cysticercus of *Tænia saginata* (after Leuckart); 4*b*, cœnurus of *Multiceps* (after Braun-Seifert); 4*c*, *Echinococcus* (after Braun-Seifert.)

frequently referred to as a *procercoid*. Soon, however, the larva comes to possess a characteristic solid or cystic appendage, derived from the region posterior to the scolex, and into which the scolex is

usually invaginated. If the appendage is a solid globular body, the larva is termed a *plerocercus* (Fig. 133, *1*); if it is a solid elongated structure, the larva is known as a *plerocercoid* (sparganum stage of *Diphyllobothrium*, Fig. 127, *2*); if the appendage is bladder-like proximally and possesses a solid caudal portion distally it is referred to as a *cysticercoid* (*Dipylidium*, *Hymenolepis*, Fig. 127, *3*); if the appendage has become entirely differentiated into a bladder-like structure surrounding the invaginated scolex it is known as a *cysticercus* (*Tænia solium*, *T. saginata*, Fig. 127, *4a*). Certain larvæ of the family **Tæniidæ**, while possessing the cysticercus-type of structure, have become uniquely modified in character, resulting in an asexual multiplication of the organism. Instead of producing a single scolex the inner wall of the cyst has become a germinative layer from which a large number of scolices arises, each scolex capable of developing into a complete marita. Such a cyst is called a *cœnurus* (*Cœnurus cerebralis*, Fig. 127, *4b*). Moreover, if the germinative layer, instead of producing scolices, gives rise to daughter cysts and these, in turn, proliferate scolices, the cyst is termed an *echinococcus* (*Echinococcus granulosus*, Fig. 127, *4c*). Such scolices are commonly referred to as hydatids.

Not only is asexual multiplication found in the cœnurus- and echinococcus-producing tapeworms but it occurs in some of the **Pseudophyllidea** as well. In *Sparganum proliferum* lateral buds are produced, which separate from the parent worm and give rise to other bud-like processes, each capable of developing into a marita. The same is true of the sparganum of *Diphyllobothrium latum* and *Sparganum mansoni*, which explains why the number of larvæ found in the second intermediate host (fish, frog, snake) of these species is many times greater than the number received from the first intermediate host. As a rule, however, multiplication in the cestodes is limited solely to egg production, so that, on the whole, the life cycle may be regarded as a metamorphosis rather than a metagenesis. In this respect it is far simpler in type than that of the digenetic (endoparasitic) trematodes and corresponds more closely to that of the monogenetic (ectoparasitic) trematodes.

In the case of the human cestodes, man is usually the definitive host. Exceptions occur in the case of *Cœnurus cerebralis* and *Echinococcus granulosus*, where man is the intermediate host. In *Tænia solium* infections man is usually the definitive host but occasionally harbors the cysticercus. *Diphyllobothrium houghtoni* is probably capable of producing both an intestinal and a somatic infection of man. In the former case, man is the definitive host; in the latter case, the intermediate host. Man is the only known definitive host of *Tænia saginata*. In *Hymenolepis nana* infections man serves both as intermediate and definitive host.

While the eggs (onchospheres) of tapeworms reach the first

intermediate host through feeding on more or less diluted fecal wastes, infection of the definitive host (or, in the case of *Diphyllobothrium,* the second intermediate host) is brought about from the ingestion of the infected first intermediate host or part of its tissue. Thus the fish or the frog incurs somatic sparganosis through consumption of the *Cyclops,* which is the first intermediate host of the infection. Man, dogs and cats incur the intestinal infection from raw consumption of the second intermediate host. *Dipylidium* and *Hymenolepis diminuta* infections in man or other mammals result from the accidental ingestion of the arthropods respectively involved as intermediate hosts. The presence of *Tænia solium* and *Tænia saginata* in man is due to eating raw flesh of "measly" pork or beef. *Hymenolepis nana* and *Echinococcus* infections in man are due to unclean habits of the infected individual. The time required for the maturing of the adult tapeworm in the human intestine varies from a few days to several weeks, depending on the species of worm.

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CHAPTER XVI.

THE CESTODES OR TAPEWORMS. CLASSIFICATION.

In contrast to the imperfect classification of the trematode group a much more satisfactory one has been developed for the cestodes. This is due, no doubt, to the fact that most of the life cycles of the common cestodes of man and domestic animals have been known for several decades, thus making it possible to evaluate both structural and biological characteristics in making up a working classification. The system adopted in this manual is an adaptation and elaboration of Monticelli's classification. The outline of the Class **Cestoda** follows:

CLASS III. CESTODA RUDOLPHI, 1808.

Parasitic organisms; adults hermaphroditic, covered with a nonciliated integument; ciliated epithelium when present confined to larvæ hatched from eggs; scolex provided with suckers and frequently with hooks; no alimentary canal; body in almost all species divided into segments.

Subclass I. Cestodaria Monticelli, 1892.

Body not divided into segments; only a single set of reproductive organs. No human representative. Example: *Archigetes sieboldi* Leuckart, 1878.

Subclass II. Cestoda (sensu stricto) Monticelli, 1892.

Body with scolex and series of segments, each containing a set of male and female reproductive organs.

ORDER I. PSEUDOPHYLLIDEA CARUS, 1863.

Scolex with a single terminal or two opposite sucking organs, never with four suckers or accessory proboscides.

Superfamily Bothriocephaloidea Braun, 1903.

Head with two elongate suckers or one apical sucker, with proboscis or rostellum; uterine pore present; genital organs not degenerate in gravid proglottids; eggs operculate, with a single shell layer; embryo (onchosphere) ciliated; larvæ require one or more intermediate hosts; adults in intestine of vertebrates.

Family DIPHYLLOBOTHRIIDÆ Luehe, 1910.

Openings of cirrus and vagina on the same surface as uterine pore. Human representatives: *Diphyllobothrium latum* (Linn., 1758); *D. cordatum* (Leuckart, 1863); *D. parvum* (Stephens, 1908); *D. houghtoni* Faust, Campbell and Kellogg, 1929; *Diplogonoporus grandis* (Blanchard, 1894); *D. brauni* (Léon, 1907); *Braunia jassyensis* Léon, 1908; larval forms, *Sparganum mansoni* (Cobbold, 1882); *Sparganum proliferum* (Ijima, 1905); *S. baxteri* Sambon, 1907, and probably other related species.

ORDER II. TRYPANORHYNCHA DIESING, 1863.

Scolex with two or four sucking grooves and also at apex four protrusile proboscides armed with many hooks. No human representative; adults in spiral valves of Selachians. Example: *Tetrarhynchus bisulcatum* (Linton, 1889).

ORDER III. TETRAPHYLLIDEA CARUS, 1863.

Scolex with four sucking cups; vitellaria with numerous follicles. No human representative; adults in alimentary canal of fishes and reptiles. Example: *Dinobothrium plicatum* (Linton, 1905).

ORDER IV. CYCLOPHYLLIDEA BRAUN, 1900.

Scolex with four cup- or saucer-shaped suckers, and in the center an apical organ or rostellum of varied form; vitellaria a single mass usually posterior to the ovary.

SUPERFAMILY TÆNIOIDEA ZWICKE, 1841.

Body flattened; suckers four, simple; egg without operculum, with one or more shell layers; embryo (onchosphere) not ciliated; larvæ in invertebrates or vertebrates; adults in intestine of vertebrates.

Family I. ANOPLOCEPHALIDÆ Cholodkowsky, 1902.

Scolex unarmed, without rostellum; suckers large, unarmed; neck region absent. Human representative: *Bertiella satyri* (Blanchard, 1891).

Family II. DIPYLIDIIDÆ Luehe, 1910.

Rostellum if present armed; suckers unarmed; uterus broken up into egg-capsules; genital organs double. Human representative: *Dipylidium caninum* (Linn., 1758).

Family III. DAVAINEIDÆ Fuhrmann, 1907.

Rostellum cushion-shaped, armed with numerous hammer-shaped hooks in two rows; suckers armed; uterus broken up into egg capsules. Human representatives: *Davainea madagascariensis* (Davaine, 1869); *D. formosana* Akashi, 1916; *Raillietina asiatica* (v. Linstow, 1901).

Family IV. HYMENOLEPIDIDÆ Railliet and Henry, 1909.

Segments usually broader than long; testes one to four; genital pores unilateral; uterus persistent, sac-like. Human representatives: *Hymenolepis diminuta* (Rud., 1819); *H. nana* (v. Siebold, 1852); *Drepanidotænia lanceolata* (Bloch, 1782).

Family V. TÆNIIDÆ Ludwig, 1886.

Scolex armed or unarmed; uterus with median longitudinal stem and lateral branches; genital pores irregularly alternating. Human representatives: *Tænia solium* Linn., 1758; *T. saginata* (Goeze, 1782); *T. confusa* Ward, 1896; *T. africana* v. Linstow, 1900; *Multiceps multiceps* (Leske, 1780); *M. glomeratus* Railliet and Henry, 1915; *Echinococcus granulosus* (Batsch, 1786).

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CHAPTER XVII.

THE PSEUDOPHYLLIDEAN CESTODES.

ORDER PSEUDOPHYLLIDEA CARUS, 1863.

THE cestodes belonging to the Order **Pseudophyllidea** are characterized by having a spoon-like scolex, hollowed out on opposite surfaces to form suctorial grooves. In the superfamily **Bothriocephaloidea** Braun, 1903, to which all of the human species of this group belong, the uterus is provided with a pore, the eggs are operculate, with a single shell layer, and the onchosphere is ciliated. The species occurring in man are further restricted to the family **Diphyllobothriidæ** Luehe, 1910, in which the rosette-shaped or coiled uterus, as well as the vagina and cirral organ, open ventrad, and the vitellaria are lateral in position.

Considerable confusion exists as to the number of valid species of the genus *Diphyllobothrium* in mammalian hosts. This point can be settled only by a careful morphological study of the adult worms in conjunction with life history investigations.

GENUS DIPHYLLOBOTHRIUM COBBOLD, 1858.

(genus from *δί*, two, *φύλλον*, leaf, and *βοθρος*, groove or sucker).

1. **Diphyllobothrium latum** (Linnaeus, 1758) Lühe, 1910.

Synonyms.—*Tænia lata* Linn., 1758; *Tænia vulgaris* Linn., 1758; *Tænia membranacea* Pallas, 1781; *Tænia tenella* Pallas, 1781; *Tænia dentata* Batsch, 1786; *Tænia grisea* Pallas, 1796; *Bothriocephalus latus* (Linn., 1748) Bremser, 1819; *Dibothrium latum* (Linn., 1748) Diesing, 1830; *Bothriocephalus balticus* Küchenmeister, 1855; *Bothriocephalus cristatus* Davaine, 1874; *Bothriocephalus latissimus* Bugn., 1886; *Dibothriocephalus latus* (Linn., 1748) Lühe, 1899; *Bothriocephalus tænioides* Léon, 1916; *Dibothriocephalus minor* Cholodkowsky, 1916.

Historical and Nosogeographical.—*Diphyllobothrium latum*, the "broad fish tapeworm" of Central and Northern Europe, was recognized as a species of tapeworm different from *Tænia* even in pre-Linnæan times. Commonly referred to in the literature as "*Dibothriocephalus latus*," it requires to be differentiated from the genus *Dibothriocephalus* both biologically and morphologically. (The genus *Dibothriocephalus* occurs in the adult stage only in the intestine of fishes; *Diphyllobothrium* is found only as a sparganum

larva in the connective tissue of fishes, and possibly higher vertebrates while its adult stage is never found in fishes but in mammals and birds.) The adult worm, *Diphyllobothrium latum*, has long been known as a common human parasite in Northern Italy, Switzerland, parts of Germany, and in the Baltic countries. Within more recent times it has been found to be a common parasite of man in Roumania, Madagascar, Turkestan, Siberia, Northern Manchuria and Japan. It has also been introduced into several new foci in North America. Except for certain districts in Africa records of its presence outside of the northern temperate zone require verification. In addition to the human host, it has been obtained from dogs and cats and other piscivorous mammals including the bear (Vergeer).

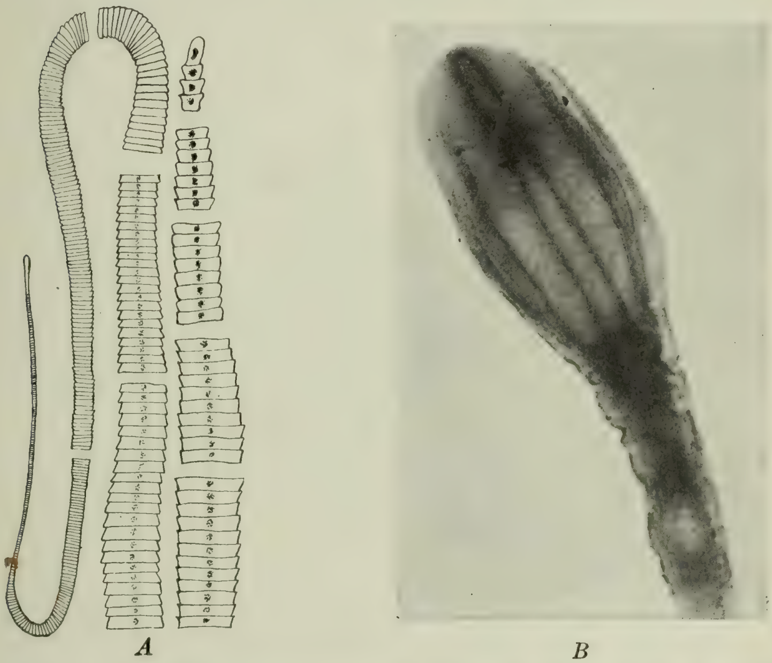

FIG. 128.—*A*, Strobila of *Diphyllobothrium latum*, two-thirds natural size (partly after Leuckart); *B*, head of *D. latum*. ×35. (From Magath.)

Structure of the Adult Worm.—When freshly expelled from the human intestine the worm (Fig. 128*A*) is ivory colored but it may become grayish on fixation. Young mature specimens may measure only 3 meters in length but older specimens may attain a length of 10 meters or more, with a total of 3000 or more segments. The scolex (Fig. 128 *B*) is small, spatula-shaped, with rather deeply sulcated lateral grooves. It measures about 1 mm. in cross-section by 2.5 mm. in length. Behind the scolex is an attenuate neck region,

having a length measurement several times that of the scolex and lacking segmentation. The distal part of the neck is the region of growth and from it there is continuously proliferated posteriorly a tape-like ribbon which develops into the proglottids or segments. In the more proximal region are the newly-formed segments. As the organism is followed further and further distad these immature proglottids become more and more fully developed until they are recognized as mature segments (Fig. 129). With the process of egg production initiated the mature proglottids become transformed into gravid segments, *i. e.*, those in which the uterus has become elongated and twisted back and forth upon itself in the characteristic "rosette" pattern to accommodate the eggs (Fig. 126, *11*). Mature and gravid segments together occupy about four-fifths of the length of the worm.

FIG. 129.—Mature proglottid of *Diphyllobothrium latum*. × 10. (Original adaptation from Claus.)

The typical mature proglottid of *Diphyllobothrium latum* (Fig. 129), such as is found in the middle third of the worm, is provided with both primary and secondary male and female reproductive organs. The testes, which are multiple, are minute spherules situated in the lateral fields on the dorsal side of the body. Each opens into a delicate vas efferens, the several vasa efferentia converging at various levels to unite into a single vas deferens, the latter originating in the mid-plane at the beginning of the posterior third of the body and proceeding anteriad as a very highly convoluted tubule, enlarging at its outer terminus to form a seminal vesicle and

ending in a muscular cirral organ, which opens on the anterior aspect of the common genital pore. The ovary is a symmetrically bilobed structure, situated on the ventral surface in the posterior third of the segment. Between its two lobes is the "shell-gland" complex. From the common genital pore there arises a narrow tubule, the vagina, which proceeds directly posteriad, coiling somewhat at its enlarged inner end to form the seminal receptacle. In the lateral fields ventral to the testes there are vitelline glands, the ducts of which converge to form right and left vitelline ducts, which, in turn, fuse into a common vitelline duct. The inner end of the vagina together with the common vitelline duct joins the oviduct to enter the oötype on the median anterior face of the shell glands. From the left anterior angle of the oötype there arises the uterus, which twists back and forth from side to side and finally terminates in a uterine or birth pore in the mid-ventral line a short distance behind the common genital pore. The amount of twisting of the uterus, *i. e.*, the "rosetting" of the uterus, depends on the number of eggs which it has been required to accommodate. Spermatozoa produced in the testes reach the vas deferens *via* the vasa efferentia and are temporarily stored in the seminal vesicle. They escape from the male system through the common genital atrium and are ordinarily transferred directly into the vagina, although the presence of a muscular cirral organ indicates that cross-insemination is possible. Once within the vagina the spermatozoa migrate inward and are stored in the seminal receptacle. The several products contributing to the formation of the egg, consisting of a naked oöcyte from the ovary, vitelline follicles from the vitellaria, spermatozoa, and "shell-gland" material, are all assembled in the oötype as they are required, and the completed egg is then pushed out into the proximal region of the uterus. The eggs in the inner portion of the uterus are necessarily less mature than those in the outer coils. In size the former are somewhat smaller and in color more hyaline.

As the uterus becomes more and more distended with eggs the sphincter guarding the birth pore becomes intermittently relaxed, so that in gravid segments there is a continuous shuttle-like discharge of eggs coördinating with egg production in the oötype. This process continues as long as the primary sexual organs are functioning, after which there is a gradual decrease in egg-laying until it ceases entirely. Unlike the cyclophyllidean cestodes the terminal gravid segments of pseudophyllidean species are never normally separated from the parent stem, but as they cease to function the distal proglottids gradually disintegrate and are finally sloughed off.

The Life Cycle of the Worm.—The eggs of *Diphyllobothrium latum* and related species when discharged from the parent worm are still immature, but are provided with abundant yolk cells to nourish the

enclosed embryo until it develops. In the case of *D. latum* the eggs are broadly oval (Fig. 130). They are usually yellow to golden-brown in color and have an operculum at one end which becomes

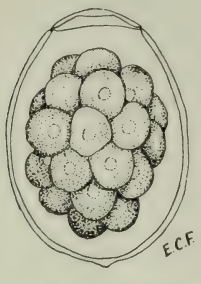

FIG. 130.—Egg of *Diphyllobothrium latum*. × 500. (Original.)

FIG. 131.—Free-swimming hexacanth embryo of *D. latum*. × 500. (After Janicki and Rosen.)

more conspicuous as the time for hatching approaches. On the average they measure 70 μ in length by 45 μ in breadth. The period for development, which occurs in water (*i. e.*, in diluted feces), varies from three to five weeks, depending upon the temperature. The hexacanth embryo, which escapes through the opercular opening (Fig. 131), is provided with a ciliated epithelium, allowing the larva to swim about as a plankton organism. The subsequent fate of the larva, according to the researches of Janicki and Rosen (1917) and Essex (1927), involves certain minute eucopepod crustaceans [*Cyclops strenuus*, *C. brevispinosus*, *C. prasinus* (Fig. 132), *Diaptomus gracilis*, *D. oregonensis*], which ingest the free-swimming larva. From the intestinal canal the larva migrates into the body cavity of this first intermediate host, becoming transformed in the course of two or three weeks into an elongated oval object, the *procercoid larva*, which measures from 50 to 60 μ in length and still possesses the three pairs of hooklets on its caudal appendage (Fig. 133). Usually only one or two such larvæ develop in a single crustacean. If now the infected crustacean is ingested by a plankton-feeding fresh-water fish, the larva is set free in the fish's stomach, and in the course of three or four days penetrates its wall and wanders through the body cavity into the flesh and connective tissue, where it becomes transformed into a *sparganum*, or plerocercoid

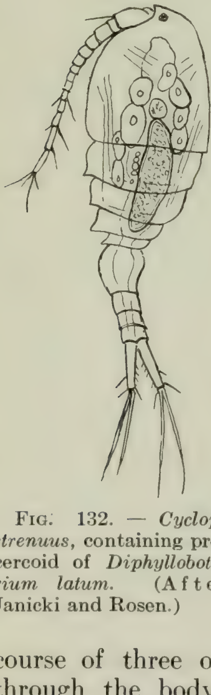

FIG. 132. — *Cyclops strenuus*, containing procercoid of *Diphyllobothrium latum*. (After Janicki and Rosen.)

larva, measuring up to 6 mm. or more in length. According to the investigations of Fuhrmann such a larva within the second intermediate host is able to multiply itself several fold by asexual methods The sparganum is characterized by an antero-posterior polarity, has an invaginated anterior end which may serve as an attachment organ and, on contraction, may appear to have a more or less pronounced pseudo-segmentation. Various fresh-water fishes, par-

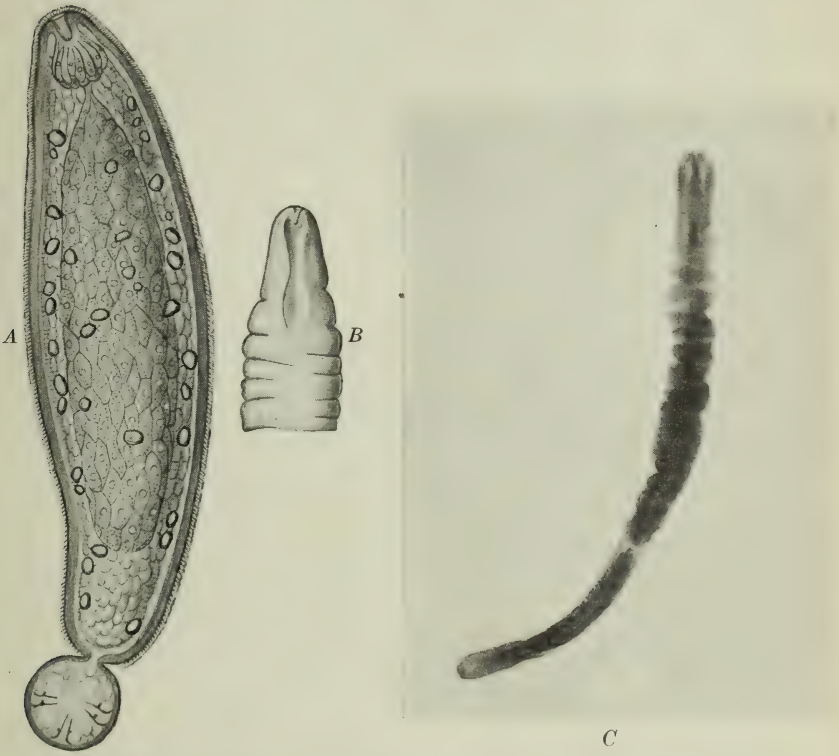

Fig. 133.—*A*, Procercoid of *Diphyllobothrium latum*, × 340; *B*, anterior end of plerocercoid of *D. latum*, × 15. (After Rosen in Braun-Seifert, Die tierschen Parasiten des Menschen); *C*, plerocercoid from wall-eyed pike, *Stizostedian vitreum*, Minnesota. × 12.5. (After Magath, Am. Jour. Trop. Med.)

ticularly those of lakes and mountain streams, serve as second intermediate hosts of the infection. Among them the following species have been incriminated: the pike (*Esox lucius*), the perch (*Perca fluviatilis*), the Miller's thumb (*Lota vulgaris*), the salmon (*Salmo umbla*), the trout (*Trutta vulgaris*), the lake trout (*T. lacustris*), and the grayling (*Thymallus vulgaris*), all from Europe; the rainbow trout (*Onchorhynchus perryi*) from Japan; the barbel (*Barbus vulgaris*) from Lake N'gami in Africa; and from northern

North America the northern pike, *Esox lucius*, the wall-eye, *Stizostedion vitreum*, the sand-pike, *S. canadense griseum*, and the burbot, *Lota maculosa.* In the United States infested fishes have been found only in certain inland lakes near Ely, Minnesota, and in the copper-mining region of the upper peninsula of Michigan. In Canada the infection is much more widespread, having been found in Lake Winnipeg, Lake Winnipegosis, Lake Manitoba, Lake of the Woods, Lac la Biche, Lesser Slave Lake, and several smaller bodies of water. (*Fide* Dr. Teunis Vergeer.) The wide distribution of these piscine hosts in North America makes the possible dispersal of this parasite a serious public health menace. On consuming insufficiently cooked flesh and possibly the roe (caviar) of infested fish man incurs the infection, the worm proceeding to develop within his intestinal tract and maturing in five or six weeks after exposure, at the end of which time eggs first appear in the feces.

Pathogenicity and Symptomatology.—The presence of *Diphyllobothrium latum* in the human intestine at times gives rise to a definite clinical picture commonly known as "dibothriocephalus-anemia." The patient, who gives a past history of having eaten uncooked or rare fish, first experiences a condition of malaise and possibly of jaundice. On physical examination there is a noticeable anemia, and possibly slight hemorrhage of the oral mucosa. There may be slight edema of the face and joints. Blood examination shows an erythropenia (1,400,000 to 2,000,000) with nucleated red cells, anisocytosis and poikilocytosis, a reduction in the white cells, with a more or less pronounced eosinophilia. The hemoglobin percentage may be as low as 25 or 30. There is frequently a slight irregular elevation of temperature. Some clinicians believe that the symptoms are due to the absorption of by-products from the degenerating dead proglottids of the worms, but the majority favor the view that the living worm secretes a substance toxic to the host. In other cases of infection, perhaps a majority, there are no clinical symptoms.

Diagnosis.—Based on the recovery of the characteristic eggs (Fig. 130) from the feces of the patient.

Therapeusis.—*Filix-mas*, in capsules (six 10-minim doses at half-hour intervals), followed by a saline purgative three hours later; or carbon tetrachloride c. p. not in excess of 3 cc., followed in three hours by a saline purgative. In severe cases, extreme care should be taken to prevent absorption of the drug into the system.

Prognosis.—Good, provided the worms are completely removed. The symptoms clear up following evacuation of the worms, the blood picture returns to normal, and the patient proceeds to an uneventful recovery.

Prophylaxis.—Thorough cooking of all fish in suspected areas. Public health officials in non-endemic areas should erect barriers to prevent its introduction.

2. **Diphyllobothrium cordatum** (R. Leuckart, 1863).

Synonyms.— *Bothriocephalus cordatus* R. Leuckart, 1863; *Dibothriocephalus cordatus* (R. Leuckart, 1863).

Diphyllobothrium cordatum is a common parasite of the seal, the walrus and the dog in Greenland and Iceland and of the dog in Japan, and is a potential human parasite, one human case being on record. Its distinguishing characteristics (Fig. 134) are the compressed cordate scolex, with suctorial grooves on the dorsal and ventral surfaces, the almost complete absence of a neck, and the transversely compressed proglottids, each having a uterine rosette of six to eight coils (Fig. 126, *10*). The operculate eggs are broadly oval, measuring 75 μ in length by 50 μ in breadth. The entire

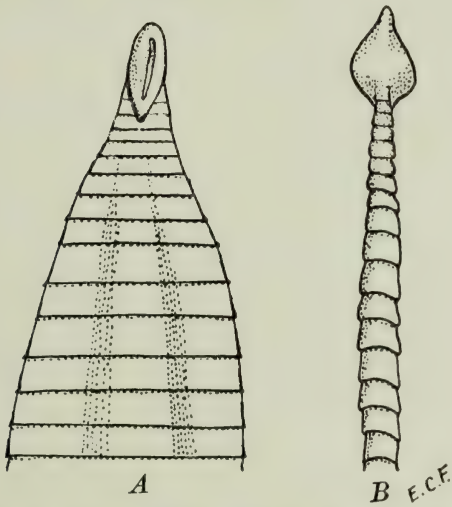

FIG. 134.—*Head of Diphyllobothrium cordatum*, from dog. × 12. (Original.)

worm has a length of 1 to 1.3 meters. The life cycle of the organism is unknown but fishes are believed to be the second intermediate host.

Pathogenicity and Symptomatology.—Unknown.

Diagnosis.—On the basis of finding the eggs in the stool of a suspected patient.

Therapeusis.—Unstudied, but *filix-mas* is probably specific.

Prophylaxis.—Abstinence from eating raw fish.

3. **Diphyllobothrium parvum** (Stephens, 1908).

Synonym.— *Dibothriocephalus latus* Stephens, 1908.

This tapeworm, which was found once by Elkington in a Syrian who had recently immigrated to Tasmania, was described as a new

species on the basis of its smaller size and different egg measurement (av. 59.2 by 40.7 μ) from *D. latum*. The scolex was not recovered. Some helminthologists believe it to be a dwarfed *D. latum* and this is quite possible. A second case harboring this worm has been reported by Léon (1915) from Roumania. Yoshida (1924) has described a third specimen from Japan. Stiles and Hassall (1926) also record this species from Persia and from Minnesota (U. S. A.). In none of these cases has the head been obtained. Magath (1929) has produced the entire strobila in experimentally infected dogs in Minnesota, and feels that the worm is an undersized *D. latum*.

Pathogenicity and Symptomatology.—Unrecorded.

Diagnosis.—On the basis of finding the eggs of the parasite in the stool.

Therapeusis.—*Filix-mas*, as indicated for *Diphyllobothrium latum*.

Prophylaxis.—Abstinence from eating raw fish or other flesh infested with the sparganum larvæ.

4. **Diphyllobothrium houghtoni** Faust, Campbell and Kellogg, 1929.

Synonym.—*Diphyllobothrium mansoni* (Cobbold, 1882) of Faust and Wassell, 1921.

This pseudophyllidean tapeworm has thus far been found only in China. It has been recovered from the intestine of man in Shanghai and Kiukiang (Central Yangtze drainage), from the intestine of the dog in Wuchang and of the cat in Peking. The strobila is much smaller and more delicate than that of *Diphyllobothrium latum*, measuring in length from 85 cm. (human material) to 110 cm. (canine material). The scolex (Fig. 135) is spatulate in contour, oval in transverse section, and measures about 1 mm. in length by 0.4 to 0.5 mm. in breadth. There is only a slight constriction between the scolex and the cervical region. The bothria are poorly developed and serve to form only a shallow sucking groove on either side of the scolex. The most distal gravid proglottids (Fig. 136) are slightly broader than long, rectangular in outline, and measure 3 to 3.5 mm. in breadth by 2.7 to 3.2 mm. in length. The vitellaria are minute, conspicuously lobose glands, numbering about 3600. The testes are much larger, and are oval in contour, with entire margins and with their longer axis in the horizontal plane. There are from 200 to 350 in each proglottid. Both the vitellaria and testes are compactly distributed throughout the lateral fields; they encroach mesad on the uterine coils and coalesce in the anterior field to form a deep arch over the male genital opening. The latter lies nearly one-third the distance from the anterior margin of the proglottid. It is provided with a large conspicuous sphincter. The vaginal opening lies close behind the male opening, while the uterine pore is situated on the ventral side of the terminal uterine

coil, an appreciable distance behind the other two genital openings. The two ovaries constitute a rectangular mass which lies dorsal to the inner proximal coils of the uterus. There are four and a half to seven loops of the outer uterine tube, placed compactly on one another; they are equally broad except for the terminal loop which is more swollen in contour. The inner coils of the uterus, which contain the less mature eggs, are much smaller in diameter and form a compressed rosette. The eggs are ellipsoidal in shape, each with a rounded conical operculum, and measure 57 to 66 μ in length by 33 to 37 μ in transverse diameter.

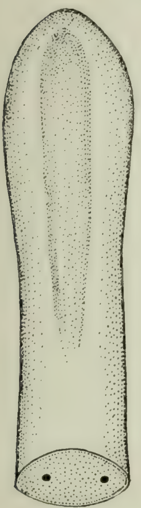

Fig. 135

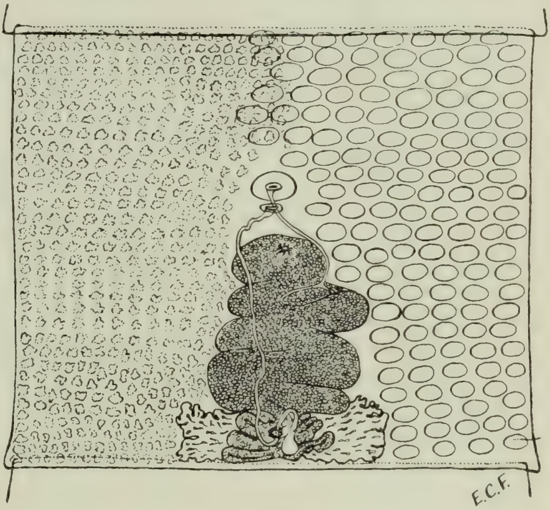

Fig. 136

Fig. 135.—*Diphyllobothrium houghtoni*, scolex greatly enlarged. (Original.)

Fig. 136.—*Diphyllobothrium houghtoni*, gravid proglottid, showing vitellaria on left, testis on right. × 15. (Original.)

The life cycle of this species is unknown but the first intermediate host is probably a *Cyclops* or other species of eucopepod crustacean and the second intermediate host, some vertebrate in which the sparganum stage develops, and which is consumed raw by the definitive host. The sparganum of this species is probably capable of parasitizing man.

Pathogenicity and Symptomatology.—Unstudied.

Diagnosis.—On the basis of finding the eggs in the patient's stool. These eggs can be readily differentiated from those of *D. latum* and *Diplogonoporus grandis*, both of which are larger, and are much broader and more rounded, but they cannot be specifically differentiated from those of several species of *Diphyllobothrium* common in canine and feline hosts in the Far East.

Therapeusis.—The adult worms may be expelled by the administration of *filix-mas.*

Prophylaxis.—Abstinence from eating the raw flesh of animals harboring the sparganum stage of this worm.

5. **Diphyllobothrium mansoni** (Cobbold, 1882) Joyeux, 1928.

Synonyms.—*Ligula mansoni* Cobbold, 1882; *Bothriocephalus liguloides* Leuckart, 1886; *Bothriocephalus mansoni* (Cobbold, 1882) Blanchard, 1888; *Dibothrium mansoni* (Cobbold, 1882) Ariola, 1900; *Sparganum mansoni* (Cobbold, 1882) Stiles and Tayler, 1902; *Plerocercoides mansoni* (Cobbold, 1882) Guiart, 1910; *Sparganum raillieti* v. Rátz, 1912; *Dibothriocephalus mansoni* (Cobbold, 1882) Manson-Bahr, 1925.

Historical and Nosogeographical.—This pseudophyllidean tapeworm, first recovered by Manson in its larval stage in 1882 at the autopsy of an Amoyese, and commonly designated as "Manson's tapeworm," is frequently found in its adult stage in dogs and cats and their wild relatives in the Sino-Japanese area, extending as far south as French Indo-China. This species has also been obtained from the cat in Porto Rico (Cram, 1926). The adult stage is probably not infective for man (Faust, Campbell and Kellogg, 1929). On the other hand, the sparganum stage has been found to be parasitic in man over a wide area in the Far East, the usual types of the infection being subcutaneous and ocular sparganosis. Upward of a hundred human cases are on record, including those from South China, Japan, Formosa and particularly Tonkin; the number of diagnosed cases with ocular sparganosis is on the increase in Tonkin.

Structure of the Adult Worm.—The adult *Diphyllobothrium mansoni* which is commonly a parasite in the middle third of the small intestine of the dog, the wolf, the fox, the cat, the wild cat, the leopard and the tiger, resembles *D. latum* in its general appearance, but differs from the latter in being much more delicate in its structure and in seldom attaining a length of more than 60 cm. to a meter. The present author is in general agreement with Joyeux and Houdemer (1928) with respect to the points of specific differentiation of *D. mansoni.* The scolex (Fig. 137) measures 1 to 1.5 mm. in length by 0.4 to 0.8 mm. in breadth, is nearly quandrangular in transverse section and has the free margins of the bothria well developed. The proglottids are broader than long except at the distal end of the strobila, where they may be approximately square. They are somewhat smaller than those of *D. houghtoni.* The testes and vitellaria are situated in the lateral fields but occasionally coalesce anteriorly. The testes number 380 to 540 per segment. The uterus describes three to five loups in its ascent from the oötype to the uterine pore. The three genital orifices are all in the median line.

The cirral organ extends far toward the dorsal margin of the proglottid. The vaginal pore is much nearer to the male orifice than it is to the uterine pore. The eggs vary considerably in size; they measure 52 to 68.5 μ in length by 32 to 43.5 μ in transverse diameter. These characters not only differentiate *D. mansoni* from *D. latum*, but also from the more nearly related species which are frequently associated with *D. mansoni* in dogs and cats. In addition to these specific features in the structure and arrangement of the reproductive organs (Figs. 135, 136), *D. mansoni* is also readily distinguished from *D. latum* in having a more narrow ellipsoidal egg (Fig. 139), which, however, cannot be distinguished from that of *D. houghtoni*.

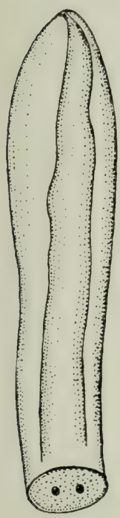

Fig. 137

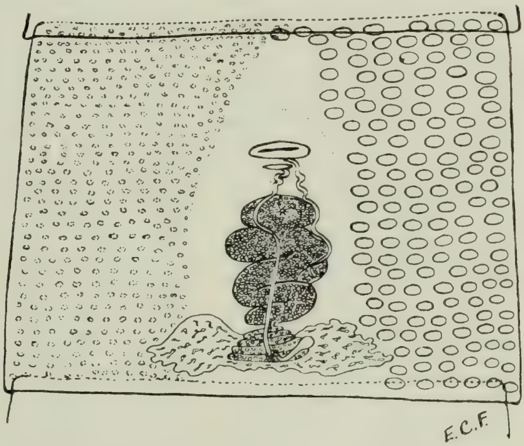

Fig. 138

Fig. 137.—*Diphyllobothrium mansoni*, scolex greatly enlarged. (After Joyeux and Houdemer, Annales de Parasitologie.)

Fig. 138.—*Diphyllobothrium mansoni*, gravid proglottid, showing vitellaria on left, testes on right. (Original.)

The sparganum stage of *D. mansoni* is much larger than that of *D. latum*. The range of second intermediate hosts is very great, comprising various species of Anura, Ophidia, birds and mammals including man.

The Life Cycle of the Worm.—The life cycle of *Diphyllobothrium mansoni* parallels that of *D. latum*, involving an eucopepod crustacean as first intermediate host, a vertebrate as second intermediate host, and a vertebrate as definite host. The eggs of the worm are discharged from the uterine pore of gravid proglottids which are attached to the parent worm and are passed in the feces. They require about five weeks in water to complete their maturity, where-

upon they hatch and the ciliated hexacanth embryo (Fig. 140) escapes through the opened operculum, swimming through the water with a Volvox-like movement. In the event that the larva is ingested by an appropriate species of *Cyclops* (*C. leuckarti*), Okumura (1919) has shown[1] that it works its way into the body cavity of the *Cyclops* and becomes transformed into a procercoid larva. If, then, the infested *Cyclops* is swallowed (in raw drinking water) by a frog, a snake, a bird or a mammal, the *Cyclops* is partially digested in the stomach of the host, the larva works its way out, penetrates through the stomach wall, and wanders along the peritoneal surface of the intestine, usually migrating to the deeper somatic muscles of the host, but at times lodging in the iliac fossæ, pleural cavity, the lumbar region (including the perirenal tissues), the urethra, etc. In these foci the larvæ (Figs. 141, 142) become metamorphosed into the sparganum type, which cannot be distinguished from the

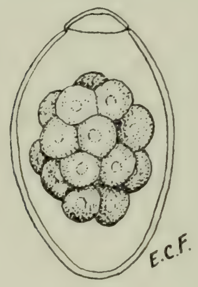

FIG. 139.—Egg of *Diphyllobothrium houghtoni* or *D. mansoni*. × 500. (Original.)

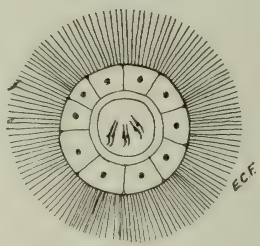

FIG. 140.—Free-swimming hexacanth embryo of *Diphyllobothrium mansoni*. × 500. (Original.)

sparganum of *D. latum* except for its larger size. Here also it may multiply by budding, the number of asexual progeny being contingent only on the space and nourishment available. Frogs and snakes, which are universally infected with these sparganum larvæ throughout the Far East, are commonly consumed by dog and cats and their wild relatives. As far as is known from experimental evidence, ingestion of the sparganum stage by a mammal always produces an intestinal and never a somatic infection.

Pathogenicity and Symptomatology. — (*a*) *The Adult Worm.* — Mature spargana of this species ingested experimentally by man have failed to produce intestinal diphyllobothriiasis (Faust, Campbell and Kellogg, 1929), although the adult worms are common in dogs and cats in endemic areas.

[1] While the experimental data obtained by Okumura undoubtedly hold true for *D. mansoni*, it is not unlikely that this investigator was working with two or more species of *Diphyllobothrium*, including *D. decipiens* and *D. okumurai*.

(*b*) *The Sparganum.*—A number of observations has been made on the presence of the sparganum of *D. mansoni* in the human host, but these uniformly record the condition produced by the mature larva in the somatic musculature, connective tissue, or in the region of the orbit. Apparently the number of larvæ ingested with the infected *Cyclops* is small, so that the migration of the larvæ through the stomach wall and along the peritoneum to the location which they find favorable for development, is practically symptom-

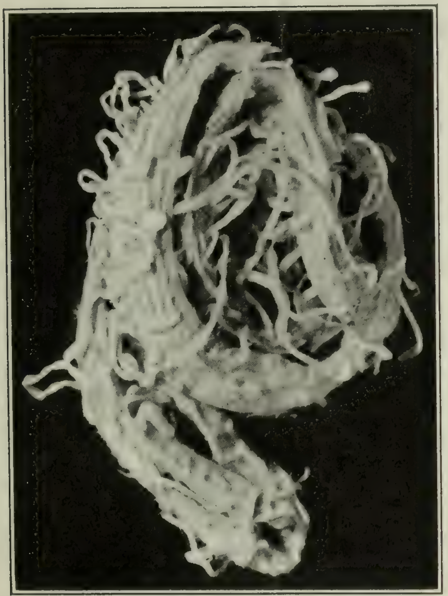

FIG. 141.—Infection of *Sparganum mansoni* in *Natrix tigrina*. Natural size. (Original photograph.)

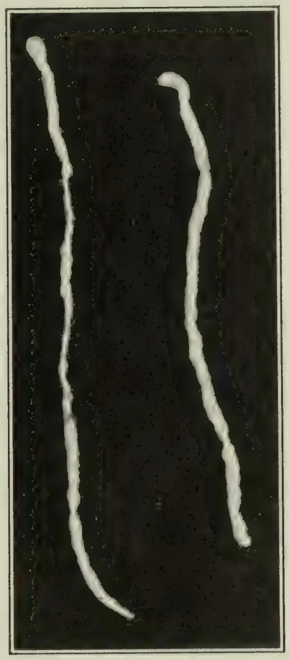

FIG. 142.—Mature specimens of *Sparganum mansoni* from experimental infection in rabbits. × 2. (Original.)

less. This development, according to experimental observations by the present author, consists of transverse fission, so that many spargana eventually develop from a single plerocercoid. This process, though undescribed in man,[1] must be accompanied by con-

[1] It is probable that human ocular sparganosis, as well as that of the subcutaneous tissue, commonly results from the transfer of spargana from infested frogs applied locally to ulcers or furuncles. Joyeux and Houdemer (1928) report such a custom in French Indo-China, while Faust, Campbell and Kellogg (1929) have found it practised in Fukien Province, China, in cases harboring *Sparganum mansoni*. It is also not unlikely that other species of *Sparganum* undifferentiable from *S. mansoni* are involved in human sparganosis in the Far East.

siderable pain. As the number of spargana increases and their channels in the subcutaneous tissue or muscle fascia become more and more extensive, the region assumes a "puffy" or edematous appearance and becomes very painful to the touch. Opening of the lesion reveals a slimy matrix, at times with a chylous exudate, within which the spargana are actively elongating and contracting. The presence of the larvæ in the tissues in and around the eye (ocular sparganosis) is characterized by intense pain, irritation and edematous swelling of the eyelids, with excess lacrymation and marked ptosis. Fibrous connective-tissue formation around the parasites has not been observed.

Diagnosis.—This can be made only after opening the lesion and obtaining the characteristic unbranched sparganum larvæ, which are frequently attached to the tissue by their scolices. They should be distinguished from *Sparganum proliferum* (Fig. 146), which is irregular in shape and usually branched. Those of the species *mansoni* (*sensu stricto*) can be differentiated from other unbranched forms commonly found in vertebrate hosts only by experimental feeding to dogs or cats and careful study of the adult worms recovered from the intestine of these experimental hosts.

Therapeusis.—This consists, wherever feasible, in removal of the spargana and draining of the lesion.

Prognosis.—Dependent entirely on the position of the parasite in the host's body and the ease with which it can be removed without injury to vital organs.

Prophylaxis.—Boiling or filtering all drinking water in endemic areas; avoiding the local application to ulcers or inflamed areas of frogs or other vertebrates infested with spargana.

Genus Diplogonoporus Lœnnberg, 1892.

(genus from διπλοις, double, γονος, reproductive, πορος, pore).

6. **Diplogonoporus grandis** (R. Blanchard, 1894) Luehe, 1899.

Synonym.—*Krabbea grandis* R. Blanchard, 1894.

This double-pored pseudophyllidean tapeworm has been recovered six times from man, in each instance from Japanese patients. The normal hosts are said to be whales. The complete worm measures from 1.4 to 5.9 meters in length. The proglottids (Fig. 126, *12*) are broad and short, measuring from 1.5 to 2.5 mm. in breadth by 0.45 mm. in length. The genital pores and uterine openings are situated in paired ventral grooves lateral to the mid-line. The uterus of each of the two genital sets in each proglottid consists of only a few loops. The operculate eggs (Fig. 143) are broadly oval, dark brown in color, and measure 63 to 68 μ in length by 50 μ in cross-section. The life cycle is unknown but fishes are suspected to be the second intermediate hosts.

Pathogenicity and Symptomatology.—Colicky pains in the abdomen, progressive secondary anemia, accelerated pulse rate (120), lassitude, alternating diarrhea and constipation, all are common symptoms of the infection.

Diagnosis.—On the finding of the characteristic eggs, or a ribbon of the even more characteristic proglottids passed in the stool after the administration of a saline purge.

Therapeusis.—*Filix-mas* as indicated for *D. latum.*

Prophylaxis.—Unknown, but the history of one of the cases is suggestive of infection from salt-water fish.

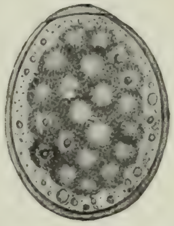

Fig. 143.—Egg of *Diplogonoporus grandis.* × 440. (After Kurimoto, in Braun and Seifert, Die tierischen Parasiten des Menschen.)

7. **Diplogonoporus brauni** Léon, 1907.

Three specimens of this species of tapeworm (Fig. 144) have been recovered from two patients in Roumania. The worm, which has the appearance of a thick grayish ribbon, measures only 12 cm. in length. The segmentation is marked by

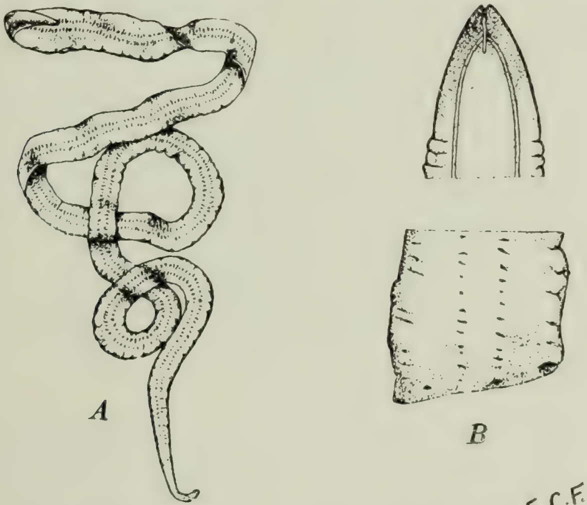

Fig. 144.—*Diplogonoporus brauni.* *A*, complete worm, natural size; *B*, head and anterior end, × 4. (After Léon, in Brumpt, Précis de Parasitologie.)

slight transverse rings and the pedunculated scolex possesses a dorsal and a ventral suctorial slit. The neck region is very inconspicuous. The genital openings together with the genital apparatus for each proglottid are paired. Genital atria are said to be lacking. The eggs are operculate and are described by Braun (1925) as being very small. The life cycle of the organism is unknown.

Pathogenicity and Symptomatology.—Patients harboring this worm are said to suffer from anemia.

Diagnosis.—From the recovery of the ripe proglottids of the parasite in the stool.

Therapeusis.—*Filix-mas* as indicated for *Diphyllobothrium latum.*

Prophylaxis.—Unknown, but the infection is probably incurred from consumption of raw fresh-water fish.

GENUS BRAUNIA LÉON, 1908.
(genus named for Professor Max Braun).

8. **Braunia jassyensis** Léon, 1908.

This tapeworm, belonging to the subfamily **Ligulinæ** of the family **Diphyllobothriidæ,** is the sole representative of its group reported from man. A specimen was obtained from a railway employee in Jassy, Roumania in 1908, and another from the same locality in 1916. It is a fleshy, ribbon-shaped parasite (Fig. 145), measuring 18 to 20 cm. in length and 8 to 12 mm. in breadth. The scolex is triangular in shape and the two suckers possess shallow grooves. There is no neck region. Externally the segmentation of the worm is hardly perceptible, but internally it is distinct. On both the dorsal and ventral sides there is a median longitudinal sulcus, extending the entire length of the worm. The ovary is branched, with a single median stem. The testes are arranged in two rows on the dorsal side. The eggs are not described.

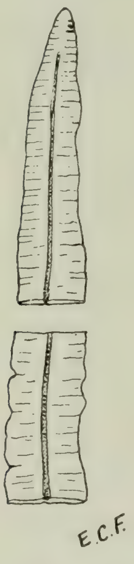

FIG. 145. — *Braunia jassyensis*, anterior end, natural size. (After Léon, in Brumpt, Précis de Parasitologie.)

Pathogenicity and Symptomatology.—"Diarrhea and headache" are recorded as symptoms.

Diagnosis.—From the recovery of the ripe proglottids in the stool.

Therapeusis.—*Filix-mas* is probably specific.

Prophylaxis.—Unstudied. One patient was a fish merchant, suggesting raw fish as a source of infection.

LARVAL PSEUDOPHYLLIDEAN CESTODES OCCURRING IN MAN.

GENUS SPARGANUM DIESING, 1854.
(genus from σπαργανίον, ribbon).

9. **Sparganum mansoni.** See *Diphyllobothrium mansoni* (above).

10. **Sparganum proliferum** (Ijima, 1905).

Synonyms.—*Plerocercus prolifer* Ijima, 1905; *Sparganum* (*Gatesius*) *proliferum* (Ijima, 1905), Stiles, 1908.

This larval pseudophyllidean tapeworm was first recovered from the subcutaneous tissues of a woman living near Tokyo. Three other cases have been found in Japan and one (a fisherman) from Manatee, Florida.

The sparganum (Fig. 146) is a polymorphous larva; it is elongate in shape with an antero-posterior polarity, the apical end being capable of eversion or inversion. Frequently there are lateral processes which are from time to time budded off from the sparganum, and develop into new larvæ.

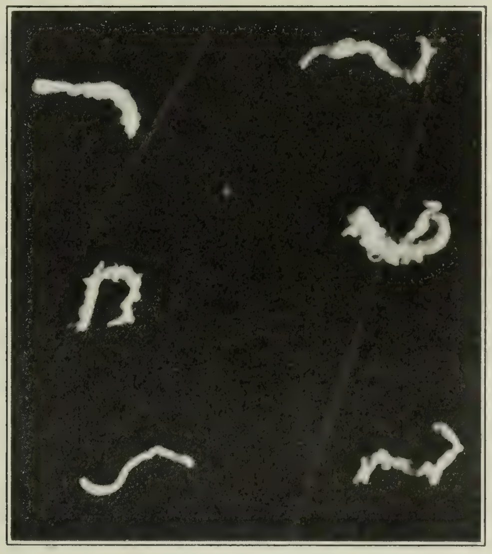

FIG. 146.—*Sparganum proliferum.* × 2. (Original photograph.)

In the cases described the spargana were found by the thousands in the subcutaneous tissues and the intermuscular fasciæ, as well as in the walls of the alimentary canal, mesentery, kidneys, lungs, heart and brain. The adult stage of the organism and its life cycle are unknown.

Pathogenicity and Symptomatology.—Nothing is known of the migration of the larvæ from the intestinal tract to the various foci throughout the body where they settle down and increase their kind by lateral budding. However, the tremendous numbers of larvæ recovered from the cases which have come to autopsy indicate the almost unlimited potentiality of asexual multiplication. The infestation finally becomes so serious that the host tissue is trans-

formed into honeycombed lesions (Fig. 147), the presence of the parasites provoking nodule formation and attempts on the part of the host tissue to wall off the parasite. At first the affected area is edematous and yields under pressure. When involving lymph channels the infection may produce an elephantiasis of the member. Opening of each of the nodules allows the escapes of from one to several worms, together with a watery or chylous fluid. Later, however, the cyst wall becomes thickened by the deposition of fibrous tissue, so that it is firm to the touch. If the lesions are subcutaneous, the body may be covered with acneform pustules, which cause intense itching. The deeper lesions produce less definite symptoms but are the more dangerous.

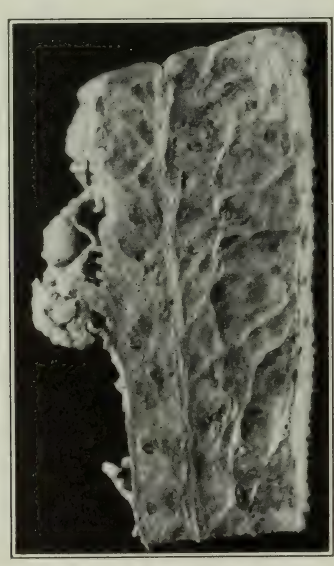

FIG. 147.—Human flesh infested with *Sparganum proliferum*. Natural size. (Original photograph of material presented by Professor T. Suzuki.)

Diagnosis.—On the expression of the characteristic larvæ from subcutaneous nodules of the infested individual.

Therapeusis.—The multiple lesions, usually involving the viscera as well as the somatic tissues, make treatment practically hopeless.

Prognosis.—Grave, particularly where primary centers are involved.

Prophylaxis.—Unknown, since the life cycle of the organism is unknown.

11. **Sparganum baxteri** Sambon, 1907.

This sparganum, which is morphologically indistinguishable from

that of *Diphyllobothrium mansoni*, was removed by Baxter from an abscess in the thigh of a native in East Africa. It may be the same species as *Sparganum mansoni*, or a closely related form.

12. **Sparganum** species.

Three cases of sparganosis in man have been reported from Australia. Although two of these cases were reported as harboring *Sparganum mansoni* (*i. e.*, *Bothriocephalus mansoni vel liguloides*, Cleland inclines to the view that they are specifically different and that their normal host is a snake or monitor. Additional cases of human infection with unbranched spargana have been recorded from Holland (Römer, 1910), British Guiana (Daniels, 1910), and Texas (Moore, 1915). The species of these spargana is *sub judice.*

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CHAPTER XVIII.

THE CYCLOPHYLLIDEAN CESTODES.

ORDER CYCLOPHYLLIDEA BRAUN, 1900.

THE cestodes belonging to the Order **Cyclophyllidea** are characterized (1) by the presence of four symmetrically arranged cup-shaped suctorial pockets on the scolex, (2) by the lateral opening of the genital atrium, (3) by the absence of a uterine pore, and (4) by the complete development *in utero* of the non-ciliated hexacanth embryo, which is housed in a non-operculate shell. The scolex is usually provided with an apical projected, the *rostellum*, which may or may not be armed with hooks. All of the human cyclophyllidean tapeworms belong to the superfamily **Tænioidea** Zwicke, 1841, which is distinguished by having non-operculate eggs with one or more shell layers, non-ciliated onchospheres and four simple suckers arranged symmetrically around the scolex.

Family ANOPLOCEPHALIDÆ Cholodkowsky, 1902.

This family contains many species of mammalian tapeworms, characterized by having an unarmed scolex and large unarmed suckers, and by the absence of a rostellum and a neck region. The only species known to occur in man are *Bertiella satyri* and *B. mucronata,* two of the six species of this genus recorded from Primates.

GENUS BERTIELLA STILES AND HASSALL, 1902.
(genus named for Dr. Paul Bert).

1. **Bertiella satyri** (Blanchard, 1891) Stiles and Hassall, 1902.

Synonyms.—*Bertia satyri* Blanchard, 1891; *Bertia studeri* Blanchard, 1891.

This species was first obtained from an orang-outang, *Simia satyri,* in Borneo. Two human cases have been reported, one a child in Mauritius (Blanchard, 1913) and the other a Bengali child (Chandler, 1925). In the former human case only fragments of the worm were available for study; in the latter both fragments and a complete worm were passed after treatment. The specimens from macaques, baboons and the gibbon are possibly also referable to this species of *Bertiella.*

The worm has a total length measurement of about 275 mm., and

a maximum breadth of 10 mm. when relaxed. The subspherical head (Fig. 148*A*) is distinctly set off from the neck. It measures 4.75 μ in transverse diameter. Apically there is a rudimentary unarmed rostellum. The conspicuous oval suckers measure 220 by 150 μ. The neck at the insertion of the head has a transverse measurement of 275 μ but narrows down to 225 μ at a distance 2 mm. behind the head where segmentation begins.

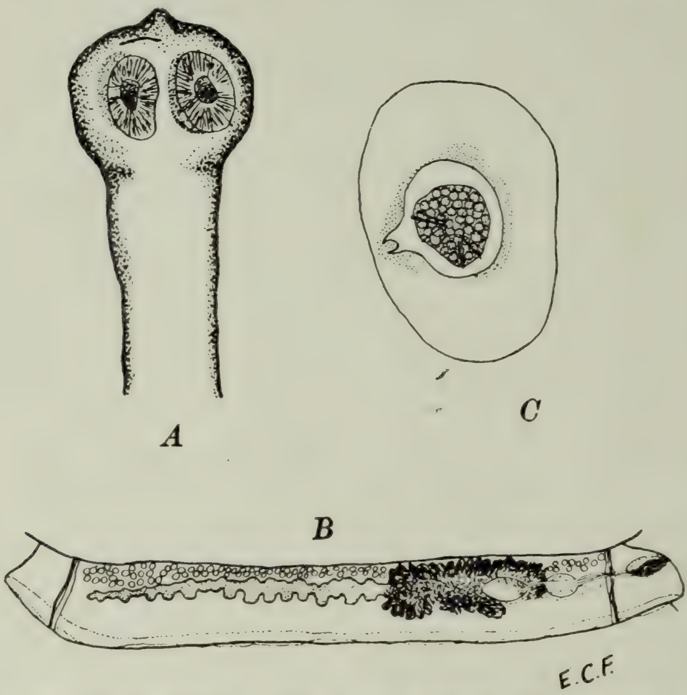


FIG. 148.—*Bertiella satyri.* *A*, head, × 52; *B*, mature segment, × 20; *C*, egg, × 600. (*A* and *B*, after Chandler, Journal of Parasitology; *C*, adapted from Blanchard.)

The mature segment (Fig. 148*B*), which contains a full complement of reproductive organs, measures about 6 mm. in breadth by 0.75 μ in length. The genital pores alternate irregularly. The crescentic ovary lies on the side of the proglottid in which the genital pore is situated, as do the "shell gland" and the seminal receptacle. The majority of the numerous testes are situated on the opposite side, while the uterus with its anterior and posterior lateral branches extends horizontally from the oötype toward the aporal margin. As the segments become more and more gravid, the uterus comes to occupy an increasingly greater portion of each segment. The testes and seminal receptacle, however, persist for a considerable

time. Finally the uterus usurps practically all of the segment. The segments are shed in group of about two dozen. The eggs (Fig. 148*C*) have an irregular crinkled oval outline, measuring 45 to 46 μ by 49 to 50 μ. The middle envelope is very delicate. The inner shell is drawn out on one side into a bicornuate apparatus. The life cycle of the worm is unknown.

The related species, *Bertiella mucronata* (Meyner. 1895) Beddard, 1911, has been reported (Cram, 1928) as an intestinal parasite of man in Cuba, the patient having lived previously in the Canary Islands. This species is also recorded from the African chimpanzee (*Pan* sp.) and from the Paraguayan black howler (*Alouatta caraya*).

Pathogenicity and Symptomatology.—Unstudied, but apparently unimportant.

Diagnosis.—On recovery of the eggs with the irregular oval outline and peculiar internal shell; or on obtaining chains of the characteristic gravid proglottids.

Treatment.—The worms are evacuated after administration of *filix-mas*.

Prophylaxis.—Unstudied.

Family DIPYLIDIIDÆ Luehe, 1910.

The cyclophyllidean family of double-pored tapeworms is characterized by having unarmed suckers, a rostellum, when present, provided with hooklets, a double set of reproductive organs for each segment and a uterus which breaks up into egg capsules. The family contains one species, *Dipylidium caninum*, which is from time to time a human parasite.

Genus Dipylidium Leuckart, 1863.
(genus from δί, two, and πύλων, gate).

2. **Dipylidium caninum** (Linnæus, 1758) Railliet, 1892.

Synonyms.—*Tænia canina* Linnæus, 1758 *pro parte; Tænia moniliformis* Pallas, 1781; *Tænia cucumerina* Bloch, 1782; *Tænia cateniformis* Goeze, 1782 *pro parte; Tænia elliptica* Batsch, 1786; *Tænia cuneiceps* Zeder, 1800; *Dipylidium cucumerinum* (Bloch, 1782) Leuckart, 1863.

This, the common tapeworm of the dog, is also frequently found in the cat, the civet cat, the hyena, the jackal, and from time to time in man. The worm, which lives in the small intestine, consists of a concatenation of elliptical segments and measures from 100 to 500 mm. in length. The head (Fig. 149*A*) is a small rhomboidal object, with a transverse diameter of 300 to 400 μ, having four deeply-cupped, oval suckers and a median anterior club-shaped rostellum, the latter being capable of protrusion to a length of 185 μ or of

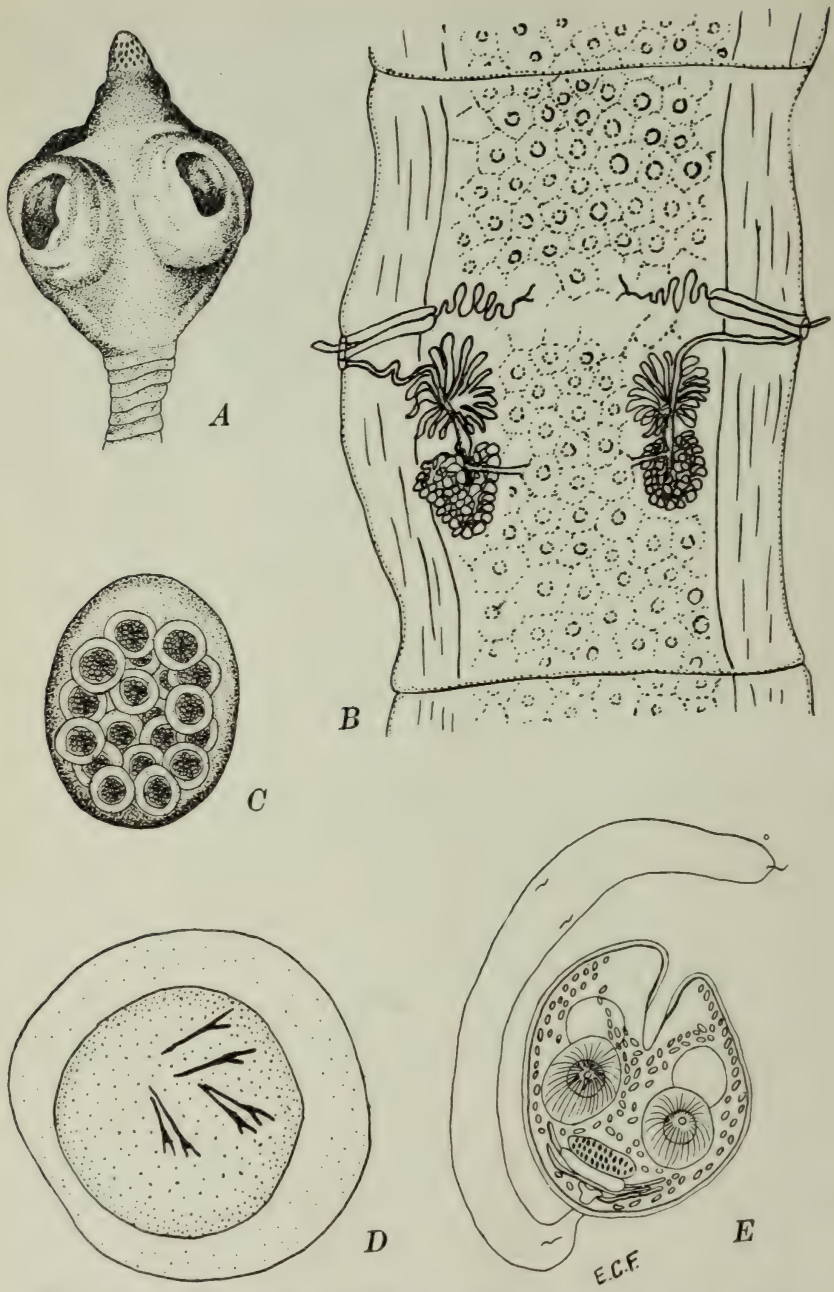


FIG. 149.—*Dipylidium caninum.* *A*, head, greatly enlarged, (adapted from Stiles); *B*, mature proglottid, enlarged (original); *C*, egg cluster in embryonic membrane (after Stiles); *D*, single egg, × 1500 (original); *E*, cysticercoid larva, greatly enlarged, (after Grassi and Rovelli, in Braun-Seifert, Die tierischen Parasiten des Menschen).

complete invagination into the head. The rostellum is armed with 3 or 4 circlets of spines, having a short curved arm and a large rounded base. The anterior series are the largest and the posterior ones the smallest. The neck is short and slender. The immature segments range from those that are shorter than broad to those that are squarish. The mature segments (Fig. 149*B*) are longer than broad and begin to assume the characteristic pumpkin-seed shape. They are provided with a double series of reproductive organs, with a genital pore on each lateral margin. Receptacula seminales are lacking. The gravid proglottids are distinguished by the unique character of the uterus which has the appearance of a polygonal block work through the median field of each segment. In each uterine pocket there is a group of 8 to 15 eggs enclosed in a mother embryonic membrane (Fig. 149*C*). The eggs (Fig. 149*D*) are spherical, measure from 25 to 40 μ in diameter and are tinged a delicate brick-red, which gives a reddish color to the gravid segments. The delicate hooklets measure 12 to 15 μ in length. The gravid segments become separated singly or in groups of two or three from the parent worm and frequently wander out through the anus. Their disintegration in the bowel liberates the groups of eggs which are usually found within the intact mother envelope.

The eggs which become lodged in the perianal hairs of infected dogs and cats are ingested by ectoparasitic insects, particularly the dog flea, *Ctenocephalus canis*, and the human flea, *Pulex irritans*, which frequently lives on the dog. The dog louse, *Trichodectes canis*, has also been incriminated. Grassi and Rovelli found that the eggs hatched out in the gut of the insect and penetrated into its body cavity, where they become metamorphosed into cysticercoid larvæ (Fig. 149*E*). These larvæ mature in this location and are transferred to the mammalian host when the insect is accidentally ingested. On digestion of the insect in the intestine of the mammal the cysticercoid is liberated, attaches itself to the intestinal mucosa, and completes its development.

The infection in dogs and cats is cosmopolitan. In man over 100 cases are known from Germany, Denmark, Italy, Switzerland, Norway, Sweden, Austria, Holland, France, England, United States, the Philippines and China.

Pathogenicity and Symptomatology.—Dogs and cats may harbor large numbers of the worms without appreciable symptoms except emaciation. Human beings are seldom infected with more than a single worm. In small children, who are most commonly parasitized, slight intestinal disturbances and reflex symptoms may develop.

Diagnosis.—On the basis of finding the gravid proglottids in the stool or migrating out of the anus; or the finding of clusters of eggs in the stool.

Treatment.—*Filix-mas*, as administered in diphyllobothriases and tæniases.

Prophylaxis.—Human infection usually results from accidental ingestion of the infected insect hosts while fondling dogs or cats infested with these ectoparasites. This is particularly true for small children, who are the most common group infected with this species.

Family DAVAINEIDÆ Fuhrmann, 1907.

This family consists of several genera which are parasitic in the digestive tract of birds and mammals. Its members are characterized by having numerous minute hooklets on the margins of the suckers as well as two or three rows of hammer-shaped hooks on the rostellum. Representatives of two genera, *Davainea* and *Raillietina*, have been recorded from man.

Genus Davainea Blanchard, 1891.
(genus named for Professor C. J. Davaine).

3. **Davainea madagascariensis** (Davaine, 1869) Blanchard, 1891.

Synonyms.—*Tænia madagascariensis* Davaine, 1869; *Tænia demerariensis* Daniels, 1895.

First discovered by Grenet in children at Mayotte in the Comores, 10 cases of human infection with this worm are now known, including 1 case from Siam, 1 from British Guiana, 1 from the island of Nossi-Be, 4 from Mauritius and 2 from the Phillipines. The worm is 25 to 39 cm. long and very narrow, with a maximum breadth of 1.4 mm. The scolex (Fig. 150*A*) has four deeply excavated closely set cup-shaped suckers, while crowded between them at the anterior end of the head is a cushion-shaped rostellum provided with about 90 hooks set in two rows. There is a marked constriction between the head and the body, but no neck region. The anterior unsegmented portion of the worm is slightly broader than the head. There are altogether from 500 to 700 segments. The immature ones are very narrow, the mature ones about one and a half times as broad as long, and the gravid ones nearly twice as long as broad. Each segment (Fig. 150*B*) contains only one set of reproductive organs, the genital pore being situated laterally near the proximal margin. A receptaculum seminis is present. The uterus consists of a mass of coiled tubules, which completely fill the entire gravid segment. These coils are crowded with 120 to 150 mother capsules, each enclosing several eggs. The eggs (Fig. 150*C*) are elliptical or spindle-shaped, measure 50 to 64 μ by 19 to 23 μ, and each contains an onchosphere measuring 8 to 15 μ in diameter. The latter has three pairs of lancet-shaped hooklets.

The life history of the organism is unknown but it is believed that cockroaches of the genus *Periplanata* serve as intermediate hosts.

Pathogenicity and Symptomatology.—Unstudied.

Diagnosis.—Based on the recovery of the characteristic proglottids or eggs.

Treatment.—Unstudied; *filix-mas* is probably effective.

Prophylaxis.—Unstudied.

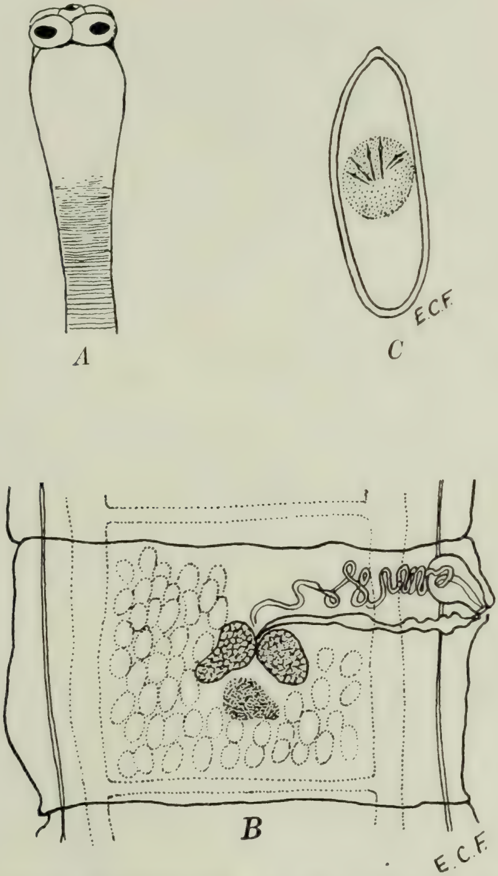


FIG. 150.—*Davainea madagascariensis.* *A*, head, greatly enlarged (after Blanchard, in Brumpt, Précis de Parasitologie); *B*, mature proglottid, × 40, original adaptation (from Garrison); *C*, mature egg, × 600 (adapted from Garrison).

4. **Davainea formosana** Akashi, 1916.

This species has been reported from Tokyo, Japan and from Formosa. It differs from *D. madagascariensis* in being somewhat longer (43 cm.), having a correspondingly larger number of segments (more than 700), in having no hooklets (?) on the suckers, in having a larger number of egg capsules (300 to 400), each capsule containing at most three eggs. The eggs are also much larger

(99 by 46 μ), while the onchosphere is 12 by 14 μ in diameter. The life cycle of the worm is unknown.

Nothing is known of the clinical history of the persons infected, except that one worm was passed spontaneously after administration of calomel.

Genus Raillietina Fuhrmann, 1920.
(genus named for Professor A. Railliet).

5. **Raillietina** (?) **asiatica** (Linstow, 1901) Stiles and Hassall, 1926.

Synonyms.—*Tænia asiatica* Linstow, 1901; *Davainea asiatica* (Linstow, 1901) Braun, 1903.

The specimen, on which this doubtful determination was made, consisted of a worm, with about 750 proglottids but without head, obtained from a case in Ashabad, Northern Persia. The egg capsules numbered 60 to 70. The size of the many eggs crowding each capsule is not stated.

Family HYMENOLEPIDIDÆ Railliet and Henry, 1909.

This family contains a very large number of species occurring in the intestinal tract of birds and mammals. The worms have segments usually broader than long. The uterus is sac-like and persistent. The majority of the species have an insect as intermediate host, but a few species require only the vertebrate in which to complete the entire life cycle. The species reported from man are *Hymenolepis nana, H. diminuta* and *Drepanidotænia lanceolata.*

Genus Hymenolepis Weinland, 1858.
(genus from ὑμήν, membranous, and λεπίς, shell).

6. **Hymenolepis nana** (v. Siebold, 1852) Blanchard, 1891.

Synonyms.—*Tænia murina* Dujardin, 1845 (*nec* Gmelin, 1790); *Tænia nana* v. Siebold, 1852; *Tænia ægyptiaca,* Bilharz, 1852; *Diplacanthus nanus* Weinland, 1858; *Hymenolepis fraterna* Stiles, 1906.

Historical and Nosogeographical.—The dwarf tapeworm of man was discovered by Bilharz in 1851 in the small intestine of a boy who had died of meningitis in Cairo. Since that time it has been found to be fairly cosmopolitan in its distribution, although it is perhaps more common in warm than in cold climates, and is much more frequently a parasite of children than of mature individuals. It is the most common human tapeworm in the Southern United States. It is now fairly well recognized that the common dwarf tapeworm of the rat and the mouse (*Hymenolepis nana* var. *fraterna*), is closely related if not identical with the human form.

Structure of the Adult Worm.—The entire worm (Fig. 151*A*) has a length measurement of only 25 to 40 mm., while its maximum diameter does not usually exceed 1 mm. The rhomboidal head (Fig. 151*B*) has a transverse measurement of about 0.32 mm., is

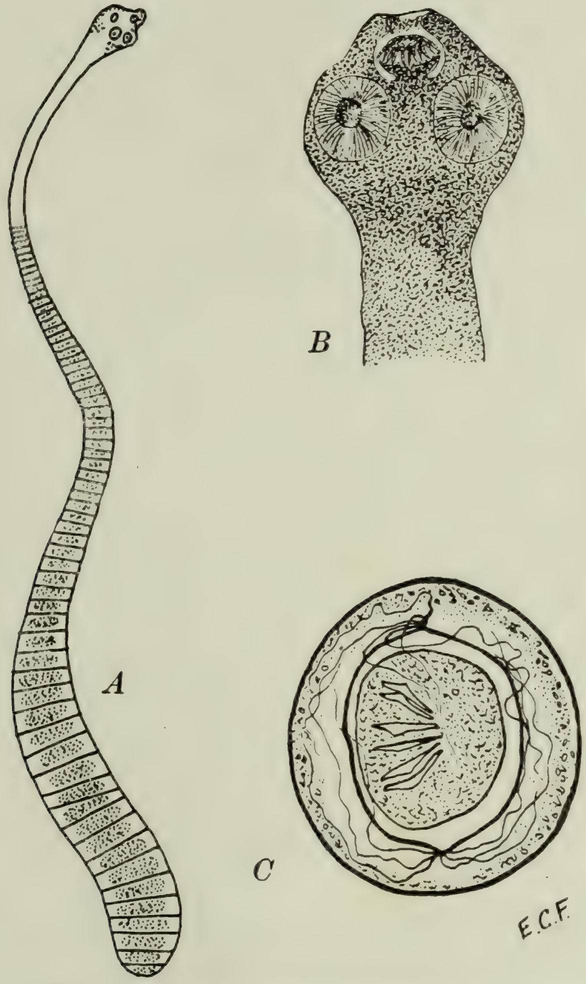


FIG. 151.—*Hymenolepis nana.* *A*, complete strobila, × 15 (original); *B*, head greatly enlarged (after Blanchard, in Brumpt, Précis de Parasitologie); *C*, egg, × 700 (after Joyeux, in Brumpt, Précis de Parasitologie.)

provided with four hemispherical suckers 80 μ in cross-section, and has a short rostellum armed with a single circlet of 20 to 30 spines. The neck is long and slender. The most proximal segments are very short; those successively more mature are longer and larger,

reaching a maximum number of 200 and a maximum size of about 0.015 to 0.03 mm. in length by 0.8 to 0.9 mm. in width. The eggs (Fig. 151*C*) are spherical or subspherical and measure 30 to 47 μ in diameter. The enclosed onchospheres, which measure 16 to 19 μ in diameter, are provided with two membranes, the outer one of which has two polar thickenings, from each of which there arise from 4 to 8 long thread-like filaments. These filaments are easily seen in viable eggs but are more difficult to demonstrate in preserved material. The three pairs of hooklets of the onchosphere are lancet-shaped. The segments drop off from the worm one by one, are partially digested, and the eggs are liberated, so that they appear separately in the stool.

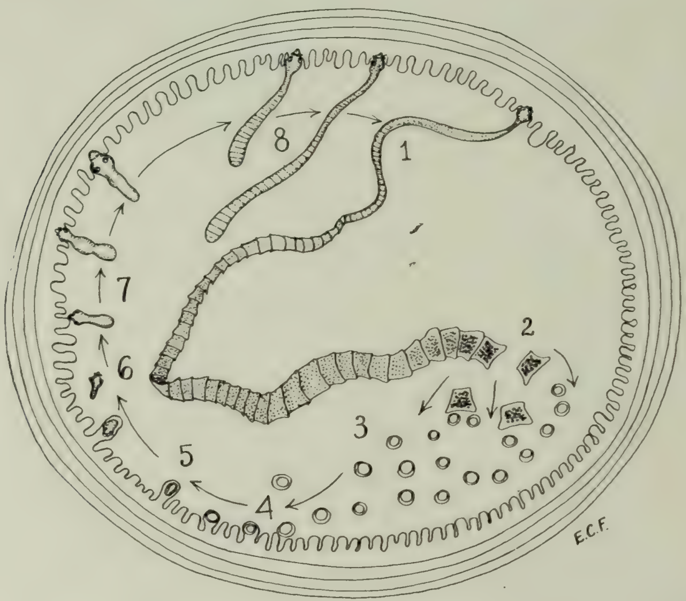


FIG. 152.—Schematic representation of the life cycle of *Hymenolepis nana*, based on natural infection in a mouse. (Original.)

The Life Cycle of the Worm.—The life cycle of *Hymenolepis nana* was first studied by Grassi and Rovelli (1887, 1892), who fed gravid segments of the rat parasite to uninfected rats and found successive stages of development in this host, until, on the thirtieth day, eggs appeared in the stool. These experiments, showing that no intermediate host was required for the complete development of the parasite, were later confirmed by Joyeux (1920) and Woodland (1924). The life cycle, which is illustrated in Fig. 152, involves the hatching of the eggs in the small intestine of the host, the penetration of the embryos into the villi of the posterior ileum, and their meta-

morphosis into young cercocysts. These, in turn, migrate out of the villi into the lumen of the gut, become attached by their heads to other villi and develop into mature worms. Controlled experiments to infect various fleas, as well as *Tenebrio molitor,* have been negative. Grassi first sponsored the view that the rat and human species were identical, basing his view on the infection of 1 out of 6 children who were fed gravid segments of the parasite in the rat. Saeki (1920), whose work has been confirmed by Uchimura (1922) succeeded in infecting rats and mice, as well as a monkey and a child, aged four years, with eggs from the human host although he was not able to infect himself. Woodland's results (1924), in infecting mice (7 out of 30) with eggs from a child's stool under carefully controlled conditions, also support the identity of the human and rat varieties. These cross-experiments suggest, however that although the parasites in the rat and man are interchangeable they may not develop as readily in the alternate host as they do in the type host in which the parent worms developed.

Pathogenicity and Symptomatology.—Although *Hymenolepis nana* is the smallest of the human tapeworms, it may give rise to severe reflex or generalized toxic symptoms, particularly in small children or when the parasite is present in large numbers. In infected children abdominal pain, with or without diarrhea, convulsions, epilepsy, insomnia and dizziness are commonly recorded. Eosinophilia is quite a constant accompaniment.

Diagnosis.—Based on the presence of the characteric ova in the stools.

Treatment.—*Filix-mas* is specific; oil of chenopodium is also efficacious in expelling the worms.

Prophylaxis.—The ability of the parasite to propagate itself without the intermediary of a secondary host and the ease with which it develops in children requires careful consideration by sanitarians. In crowded dwellings the infection is frequently contracted directly by one individual from another. Furthermore, it seems probable that a lightly infected individual is not only a "carrier" but reinfects himself so that he comes to harbor a number sufficiently large to produce clinical symptoms. Although the human infection is, in most cases, probably of human origin, infection from rodent hosts is also an important possibility. Statistical and experimental data both support the view that children are more likely to become infected than adults. However, cases up to fifty years of age have been seen by the author.

7. **Hymenolepis diminuta** (Rudolphi, 1819) Blanchard, 1891.

Synonyms.—*Tœnia diminuta* Rudolphi, 1819; *Tœnia leptocephala* Creplin, 1825; *Tœnia flavopunctata* Weinland, 1858; *Tœnia varesina* Parona, 1884; *Tœnia minima* Grassi, 1886.

Hymenolepis diminuta, the common cestode parasite of the rat and the mouse and other murine species, is an occasional human parasite. It measures 20 to 60 cm. in length and is definitely ribbon-like, increasing gradually in width from 0.5 mm. at the neck to 3.5 or 4.0 mm. at the distal end. The head (Fig. 153*A*) is small and rounded and is provided with four small deeply excavated suckers and a median anterior invagination cavity into which the unarmed pyriform rostellum is usally retracted. The proximal segments are very short but the successively more distal ones are longer, the terminal ones measuring 0.75 mm. in length by 2.5 mm. in breadth.

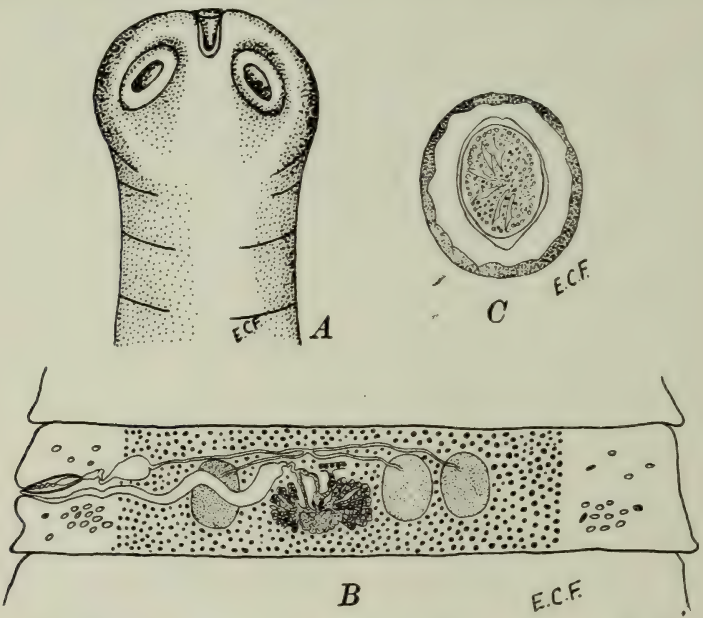


FIG. 153.—*Hymenolepis diminuta.* *A*, head, greatly enlarged (original); *B*, mature proglottid, showing male and female organs, greatly enlarged (adapted from Zschokke, in Stiles, Hyg., Lab., Marine Hosp. Bull., No. 25); *C*, egg, × ca. 300 (after Blanchard, in Brumpt, Précis de Parasitologie).

The mature proglottids (Fig. 153*B*) possess only three oval testes. The genital pore is median lateral in position and alternates irregularly. The gravid proglottids become detached from the strobila, are partially digested, and the liberated eggs are set free into the lumen of the intestine. These eggs (Fig. 153*C*) are oval in shape and have an outer measurement of 60 to 86 μ. The internal membrane, *i. e.*, that of the onchosphere, is provided with a thickening at each pole, but lacks polar filaments. The onchosphere measures 18 by 36 μ and has three pairs of lanceolate hooklets. The adult worm lives in the anterior portion of the ileum.

Various insects serve as the obligatory intermediate hosts. Among these are the lepidopteran, *Asopia farinalis* (both larva and imago), the ear-wig, *Anisolabis annulipes*, a myriopod, the rat fleas, *Ceratophyllus fasciatus* and *Xenopsylla cheopis*, the coleopterans, *Akis spinosa*, *Scaurus striatus* and *Tenebrio molitor* (larva), and the cockroaches, *Periplanata orientalis* and *Blatta germanica*. In the gut of these hosts the embryo hatches, penetrates through the intestinal wall into the body cavity and becomes metamorphosed into a cysticercoid larva. On ingestion of the insect host the cysticercoid becomes liberated, attaches itself to the intestinal wall and develops to maturity. Cases in man have been reported from India (20 cases), Italy and Sicily (6), the United States (12), Indian troups in Mesopotamia (8), Brazil (3), and 1 each in Argentina, Spain and the Belgian Congo. It is altogether probable that the infection exists in man in other localities.

Pathogenicity and Symptomatology.—Similar to that produced by other tapeworm infections. Cachexia is not an uncommon accompaniment.

Diagnosis.—Based on the presence of the characteristic ova in the stool.

Treatment.—*Filix-mas* is specific. The worms are at times evacuated spontaneously or after a cathartic.

Prophylaxis.—Human infection results from the accidental ingestion of infected insects living in cereals, such as flour or meal. Cold cereal breakfast foods, particularly when infested with the meal moth or meal worm, are subject to suspicion.

Genus Drepanidotænia Railliet, 1892.

(genus from *δρεπανίον*, lancet, and *tænia*, tape).

8. **Drepanidotænia lanceolata** (Bloch, 1782) Railliet, 1892.

Synonyms.—*Tænia lanceolata* Bloch, 1782; *Hymenolepis lanceolata* (Bloch, 1782) Weinland, 1858.

This species is a common parasite of anseriform birds. The single human infection known was reported by Zschokke in 1902, from a German youth, aged twelve years, who spontaneously evacuated two specimens. The worm has a length measurement of 5 to 13 cm. and a maximum width of 5 to 18 mm. The head is globular and small, has four deeply hollowed suckers and a cylindrical rostellum armed with a circlet of 8 lanceolate spines measuring 31 to 35 μ in length. The eggs are oval in contour, measure 50 by 35 μ, and have three envelopes, of which the innermost has polar papillæ. The intermediate host is a fresh-water eucopepod, Cyclops or Diaptomus. Human infection is undoubtedly accidental and the residence of the parasite in man is probably unstable.

CHAPTER XIX.

THE CYCLOPHYLLIDEAN CESTODES (CONCLUDED).

Family TÆNIIDÆ Ludwig, 1886.

THIS family contains the most important tapeworms infecting man and domestic animals. The worms, either in their adult or larval stage, are usually large, the adult being a parasite of the intestine of carnivora or omnivora, and the larva or bladderworm (cysticercus, strobilocercus, cœnurus or echinococcus) developing in herbivora or omnivora. The testes are multiple; the uterus has a median stem with lateral arms. The inner egg-shell is thick and is perforated with minute radiating pores.

GENUS TÆNIA LINNÆUS, 1758.
(genus from *tænia*, tape).

9. **Tænia solium** Linnæus, 1758. According to Leuckart the specific name "solium" is said to be derived from a Syrian term "schuschl," meaning a chain, which has come down through the Arabic word "susl" or "sosl," and has been turned into Latinized form, thus having no connection with the Latin word "solus," or single).

Synonyms.—*Tænia cucurbitina* Pallas, 1766; *Tænia pellucida* Goeze, 1782; *Tænia vulgaris* Werner, 1782; *Tænia dentata* Batsch, 1786; *Halysis solium* (Linn., 1758) Zeder, 1803; *Tænia armata humana* Brera, 1808.

Structure of the Adult Worm.—*Tænia solium*, the pork tapeworm or armed tapeworm, is the human representative of the subgenus *Tænia*, which contains all of the species of the genus having an armed rostellum. The worm is cosmopolitan in its distribution and is endemic wherever infested pork is eaten raw or insufficiently cooked. The adult stage is known to develop only in man. The larval stage (cysticercus) commonly occurs in the pig, occasionally in man and other primates, and rarely in sheep and dogs. The adult is found in the anterior two-fifths of the small intestine. It attains a length of from two to several meters. The scolex (Fig. 154) which is well buried in the intestinal mucosa of the infected host, is roughly quadrate, measures about 1 mm. in diameter and, in addition to the four-cupped suctorial pockets, has a rostellum provided with a double row of alternating large and small hooks numbering from 22 to 32. The suckers are slightly protuberant

and measure up to 0.5 mm. in diameter. Rarely the scolex is pigmented. In living specimens the neck has only about one-half the trans-sectional measurement of the head. The immature segments are broader than long, the mature proglottids are usually squarish, and the gravid segments are longer than broad, although never so conspicuously so as those of *Tænia saginata*. Altogether the number of segments is somewhat less than a thousand.

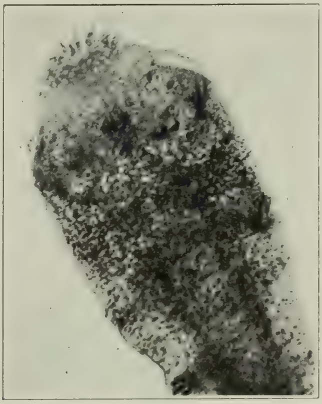


FIG. 154.—Head of *Tænia solium*. Greatly enlarged. (After Jefferys and Maxwell.)

The mature proglottid (Fig. 155) is strikingly like that of *T. saginata* (Fig. 162) and differs only in minute details. The testes are multiple follicular bodies distributed throughout the dorsal portion of the segment. Minute capillary vasa efferentia with their inner termini connected with the follicles join in dendritic fashion to form a common vas deferens, which proceeds as a slightly convoluted tubules from the mid-plane transversely to the genital atrium on the lateral margin, becoming enlarged distally into a cirral organ, containing prostate and cirrus elements. The genital atrium opens through a genital pore which possesses a powerful sphincter. The genital openings alternate irregularly from one side to the other in successive segments. Immediately posterior to the vas deferens is the vagina, which curves broadly posteriad toward the oötype. The ovary which lies in the posterior part of the segment, consists of three lobes, namely a symmetrical pair of large lobes and an accessory lobe on the side of the genital pore. The vitellaria consist of minute follicles, situated in a narrow elliptical band behind the oötype at the posterior margin of the proglottid. The common vitelline duct and the vagina join the oviduct and proceed to the oötype, which is surrounded by "shell glands." The uterus arises from the anterior face of the oötype. At first (Fig. 155) it is a club-shaped sac extending to the anterior border

of the proglottid, but as it becomes filled with eggs, lateral extensions or arms develop and these, in turn, branch once or twice, to form the characteristic gravid uterus (Fig. 126, *2*). The number of these arms is 7 to 12, a matter of considerable diagnostic value, since the gravid segments of *T. saginata* have no less than 15 such lateral evaginations.

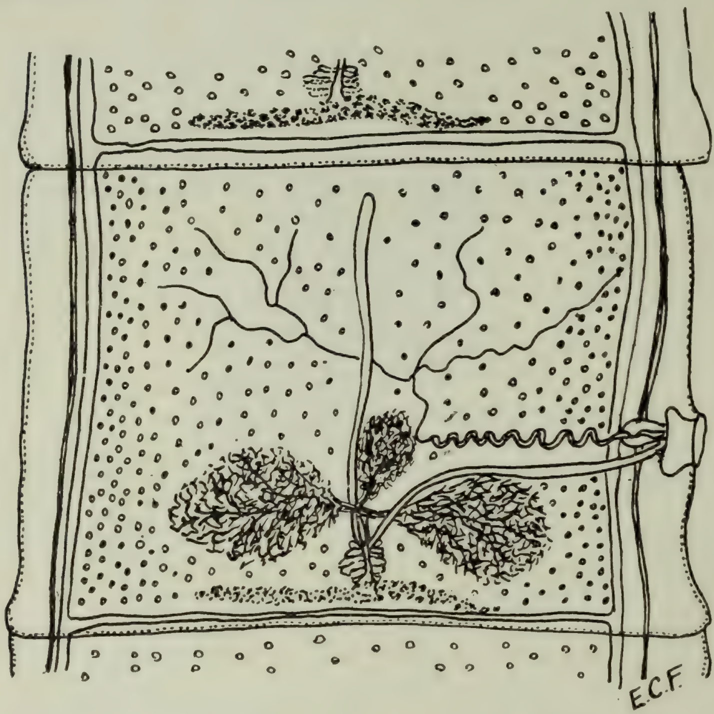


Fig. 155.—Mature segment of *Tænia solium.* × ca. 14. (After Leuckart, Parasiten des Menschen.)

The terminal gravid segments of the worm from time to time become separated either singly or in small groups from the main ribbon and are capable of independent movement, even to active migration outside the anus. Either before separation or later the uterus becomes so distended with mature eggs that it bursts open along the median ventral line and the eggs escape. These eggs (Fig. 156) are spherical or subspherical in shape, measure 31 to 38 μ in diameter, and are pale buff in color. The shell, which is a thick-walled structure perforated with minute pores, so as to resemble radial striæ, is originally provided with an outer mother embryonic membrane. Within the egg shell proper there is a fully-developed onchosphere, with its three pairs of hooklets clearly distinguishable through the shell.

The Life Cycle of the Worm.—The eggs become freed from the uterus either before or after passing out in the feces. Their subsequent history involves their ingestion by the intermediate host,

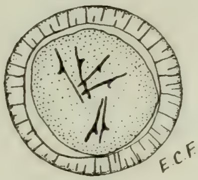


FIG. 156.—Egg of *Tænia solium*. × 666. (Original.)

in the intestine of which they hatch, whereupon the emergent embryo penetrates the intestinal wall, passes through the blood stream or the lymph channels and settles down among the muscles,

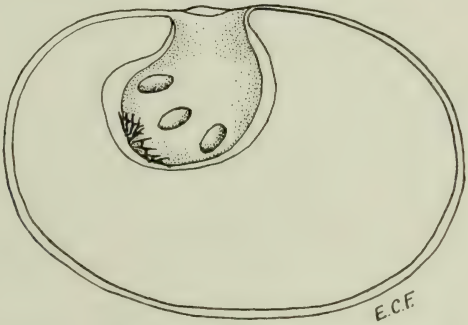


FIG. 157.—Cysticercus of *Tænia solium*. Greatly magnified. (Original.)

where the hooklets are lost and the larva becomes metamorphosed into a cysticercus. This stage (Fig. 157) is characterized by having

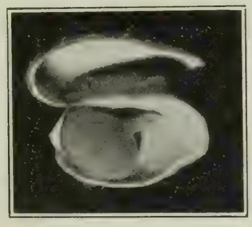


FIG. 158.—*Cysticercus cellulosæ* within adventitious outer cystic capsule, removed from biceps muscle of man. Natural size. (Original photograph.)

a head similar to that of the adult, with fully-formed hooklets, invaginated into a broad ovoid bladder, which is grossly opalescent when alive (Fig. 158) and gives the "measly" appearance to the

infested host's flesh. This cysticercus, which measures about 5 mm. in length by 8 to 10 mm. in breadth, is known as *Cysticercus cellulosæ.* Occasionally man becomes infected with the cysticercus stage of *T. solium,* apparently from contaminated food or water. Cases are also known where the human subject with a history of intestinal tæniasis becomes also infected with the cysticercus, in which case the evidence points to self-infestation. Human infection with *Cysticercus cellulosæ* may be single or multiple. The organs and tissues most commonly involved are the brain (Fig. 159), the orbit, the muscles, the liver and the lungs.

Man incurs the intestinal infection through consumption of raw or inadequately cooked infested pork. Upon passing into the lumen of the stomach the cysticercus is digested out of its fleshy matrix, the bladder of the worm is digested away, and the uninjured head passes into the small intestine, where it evaginates and becomes attached to the intestinal wall. It then develops into the adult worm, from five weeks to three months being required for the process. The adult worm may live upward of twenty-five years in the human intestine. Malformed segments are not uncommon; these usually consist of fenestrations or triangular segments intercalated among normal ones. Rarely triradiate forms have been observed, consisting of six suckers, a proportional increase in the number of hooklets, and three half-segments arranged more or less in triradial fashion around a central axis.

Pathogenicity and Symptomatology.—*A. The Adult Worm.*—Infection with the adult stage of *Tænia solium* results from the consumption of raw or rare pig flesh containing the viable *Cysticercus cellulosæ.* The worm lives in the small intestine, its head strongly anchored in the mucosa, the terminal (gravid) proglottids breaking off singly or in groups and passing out in the stool. Usually only a single worm is harbored at any one time. Ordinarily the parasite produces no grave clinical symptoms. At times, however, it may be responsible for chronic indigestion with alternating diarrhea and constipation. In persons of a nervous temperament or in children the symptoms are at times more specific, consisting of anorexia, hyperesthesia, indigestion due to malfunction of the intestinal secretions, and various nervous complications. It is believed that these disturbances are due to the absorption of toxic products of the worm. In rare cases the worm may perforate the intestinal wall and initiate peritonitis.

B. The Cysticercus.—Cysticercosis cellulosæ is not a unique condition in man. It has been known since 1558. The larvæ may develop from viable eggs introduced into the gut as an accidental contamination with food or drink, or as an auto-infection in a person who has previously become infected with the adult worm. The cysticerci of this species have been found in practically every

organ of the body, the symptoms produced varying according to their number and exact position in the invaded tissues. They have been found most frequently in the brain, where they may reside in the ventricles or in superficial cysts. Clinically this variety of the bladderworm is known as *Cysticercus racemosus* (Fig. 159). Next in the order of frequency they occur in the orbit, the musculature (Fig. 158), the heart, the subcutaneous tissues, the liver, lungs, abdominal cavity, etc. Several hundred cases of this infection are on record from Central Europe. During the first half of the nine-

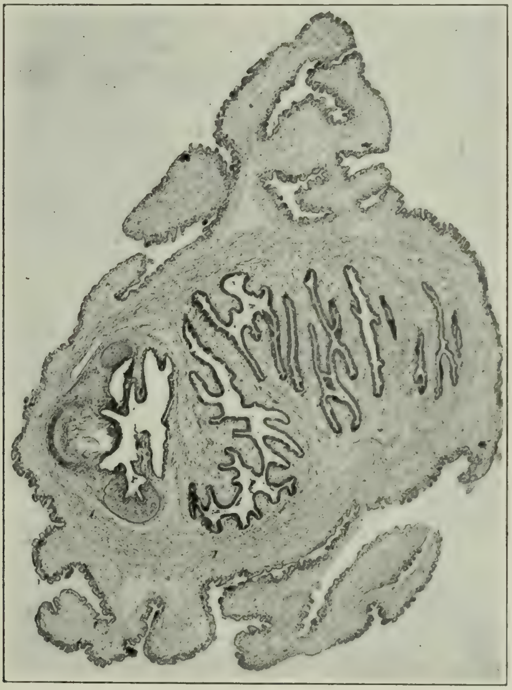


Fig. 159.—Section of *Cysticercus cellulosæ* (*C. racemosus*) removed from cortex of human brain. × ca. 10. (Photograph by Dr. C. H. Hu.)

teenth century 2 per cent of the human autopsies in Berlin showed these cysticerci. With the reduction of the adult infection in man and of the larvæ in pigs the incidence of human cysticercosis has become less frequent.

The symptoms vary according to the organs infected. Special manuals of pathology (Aschoff) and clinical parasitology (Seifert) should be consulted for detailed presentation of these cases.

Diagnosis.—A. *The Adult Worm.*—The presence of *Tænia* eggs in the stool does not permit of specific diagnosis. Recovery of gravid proglottids enables the clinician to determine without ques-

tion whether the worm is *T. solium* or *T. saginata*. In the former case the lateral arms of the uterus are usually twelve or less (Fig. 126, *2*); in *T. saginata* they number fifteen or more (Fig. 126, *1*). For immediate diagnosis the proglottids may be placed between two microscopic slides, pressed flat and examined against a strong light; or the uterus may be injected with India ink, whereupon it stands out in sharp contrast to the ivory-colored mesenchyma of the segment.

B. *The Cysticercus.*—Except in regions where cysticercosis cellulosæ is common in man, diagnosis of human infection is usually deferred until after the larvæ has been excised and examined. In the majority of cases diagnosis is never made unless the patient comes to necropsy. In superficial tissues surgical intervention is frequently indicated; where the cysticercus is lodged in vital centers, as, for example, in the brain, its presence may be inferred only from indirect evidence. Thus cysticercosis of the brain may give rise to Jacksonian epilepsy, but it must be differentiated from echinococcosis of the brain or embolisms of other types. A history of intestinal tæniasis solium in the patient is helpful in arriving at a specific diagnosis.

Therapeusis.—*A. The Adult Worm.*—*Filix-mas* administered as in *Diphyllobothrium latum* infection.

B. *The Cysticercus.*—Excision, wherever possible. Where the bladderworm is lodged in vital centers only symptomatic treatment is at times possible.

Prognosis.—A. *The Adult Worm.*—Good. After expulsion of the worm, the symptoms entirely disappear.

B. *The Cysticercus.*—Grave, except where the larva may be easily removed. There is the possibility that larvæ in inoperable foci in the body will calcify in the course of several months, or may die and be absorbed. If the patient can survive this period partial or complete recovery may result.

Prophylaxis.—This involves both personal hygiene and sanitary measures. The former involves the abstinence from eating raw or rare pork except from carefully inspected slaughter-houses and the greatest of care in handling the feces of persons known to harbor the adult *Tænia solium*. It is not likely that eggs of *T. solium* can develop into cysticerci without passing outside of the body but this possibility must also be considered. Individuals harboring the adult worm should be relieved of their infection as soon as possible. Government inspection of "measly" pork has been primarily responsible for the marked reduction of both the adult and larval infection in man in Europe and the United States. According to Newsholme (1927) provisions were instituted in England as early as 1582 against the sale of "mesell pork," punishment for disobedience of the regulation consisting of a fine or the pillory. Rigid inspection should be

instituted in all countries where the infection is not now under control and examination of pork should be extended to country slaughter-houses where the large city abattoirs are now under supervision. The present methods of pickling and smoking pork are not usually lethal to the cysticerci. Chilling is also not effective but freezing renders them non-viable.

10. **Tænia saginata** Goeze, 1782.

Synonyms.—*Tænia solium* Linnæus, 1767 *pro parte; Tænia cucurbitana* Pallas, 1781 *pro parte; Tænia inermis* Brera, 1802; *Tænia dentata* Nicolai, 1830; *Tænia lata* Pruner, 1847; *Tænia mediocanellata* Küchenmeister, 1852; *Tænia zittavensis* Küchenmeister, 1852; *Tæniarhynchus mediocanellata* Weinland, 1858; *Tænia tropica* Moq.-Tandon, 1860; *Tænia (Cystotænia) mediocanellata* Leuckart, 1863.

Also, *Tænia abietina* Weinland, 1858; *Tænia capensis* Moq.-Tandon, 1860; *Tænia lophosoma* Cobbold, 1866; *Tænia fenestrata* Huber, 1896; *Tænia hominis* Linstow, 1902.

Structure of the Adult Worm.—*Tænia saginata*, the beef tapeworm, is the principal human representative of the subgenus *Tæniarhynchus*, which contains the unarmed tæniid cestodes. It is cosmopolitan in its distribution and occurs wherever human beings consume raw or rare beef infested with the cysticercus or larval stage. The adult worm is an exclusive parasite of man. It lies in the middle length of the small intestine with its head imbedded in the mucosa. Rare cases of its migration out of its normal habitat into the pancreatic duct and into the abdominal cavity are on record. The adult worm is much larger than that of *T. solium*, due not only to the fact that the proglottids are longer, but also to the greater number of proglottids. Under favorable conditions it may attain a length of 25 meters but it usually averages not more than 10 to 15 meters and consists of about 2000 segments.

The head of *T. saginata* (Fig. 160) is quadrate-obovate in shape, measures 1.5 to 2 mm. in diameter, and is characterized by having four symmetrically arranged hemispherical suctorial pockets, which alone serve as attachment organs, since the rostellum is absent and there are no hooklets. At times the anterior axial portion is even sunken, so as to give the impression of an anterior fifth sucker. Frequently the head is covered with a characteristic melanoid pigment. The neck (Fig. 161) is about one-half as broad as the head and several times its length. Behind this there is a region of several centimeters of very immature proglottids in which the reproductive organs have not yet developed. The segments gradually increase in size, reaching a maximum width of about 12 mm. Such segments are still broader than long. The more distal proglottids are somewhat narrower (5 to 7 mm.) and measure up to

20 mm. in length. The mature proglottids (*i. e.*, those containing fully-developed reproductive organs but with the uterus still in the form of an elongate sac) are usually found some little distance

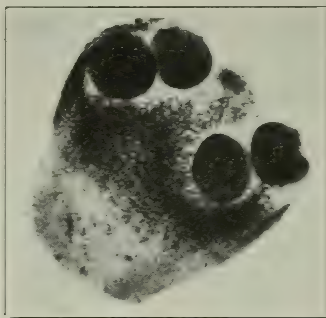


Fig. 160.—Head of *Tænia saginata*. Greatly enlarged. (After Jefferys and Maxwell.)

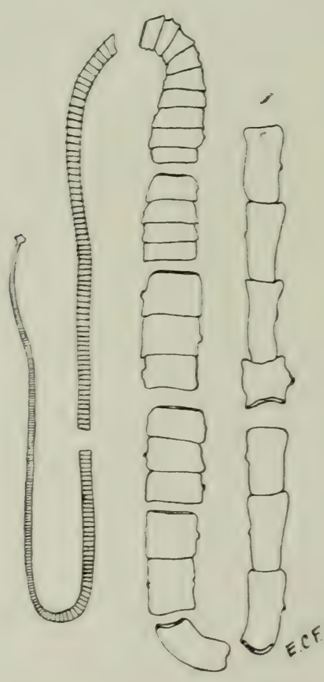


Fig. 161.—Strobila of *Tænia saginata*. Two-thirds natural size. (After Leuckart, Parasiten des Menschen.)

behind the middle of the body. Such a proglottid (Fig. 162) is somewhat broader than long. Multiple testes are distributed throughout the segment on the dorsal half, but they are most

abundant in the lateral fields. Vasa efferentia from the testes assemble in dendritic fashion toward the center of the segment, joining to form the vas deferens, which proceeds as a tightly twisted tubule directly toward the lateral margin, there to enter the cirrus pouch, which contains the muscular cirral organ. This, in turn, opens into the genital atrium. Just below the vas deferens is the vagina, with its outer extremity opening into the genital atrium and its inner opening into the anterior face of the oötype. The ovary consists of two distinct lateral branches, with an intermediate transverse collecting sinus, from which a small oviduct proceeds posteriad, joining the vagina just before the latter opens into the oötype. The vitellaria consist of a compact ellipsoidal gland,

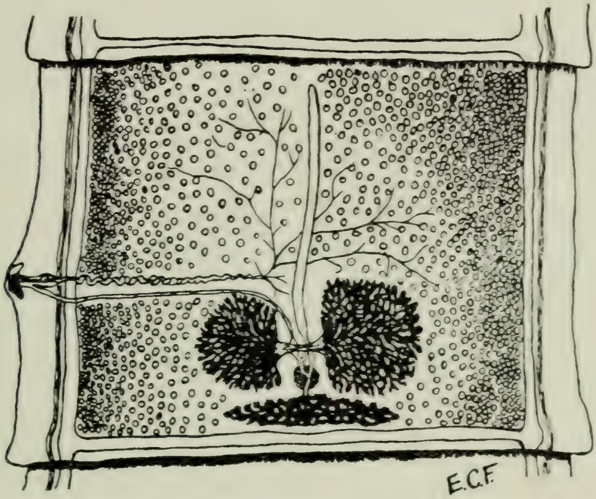


FIG. 162.—Mature proglottid of *Tænia saginata*. × 10. (After Leuckart, Parasiten des Menschen.)

situated in a transverse position immediately behind the oötype and having a short duct leading into the latter. The oötype is surrounded by a minute spherical cluster of "shell glands." The uterus in the mature proglottids is a long narrow tubular pocket, arising from the anterio-ventral face of the oötype and ending blindly near the anterior margin of the proglottid.

The process of egg manufacture begins after the proglottids have matured. After the eggs are assembled in the oötype they are shoved into the uterus, which becomes more and more distended and which soon begins to develop the characteristic lateral arms. When the segments become so gravid with eggs that the uterus assumes the characteristically branched appearance (Fig. 126, *1*), such as obtains in the terminal fifth of the worm, the generative

organs atrophy and the proglottids become mere storage-houses for the eggs. The proglottids then separate, usually one at a time, from the parent worm and for a time migrate about as independent bodies. Due to abrasion or to disintegration of the free segments, many of their uteri burst. Others migrate out of the gut or are evacuated in the feces.

The Life Cycle of the Worm.—The eggs in the gravid segments are already fully developed. While within the uterus each egg is provided with a mother embryonic membrane (Fig. 163 *A*), which is distinguished by having a pair of delicate polar processes. On extrusion from the uterus this outer membrane is soon lost, so that the egg commonly recovered from the feces is characterized by

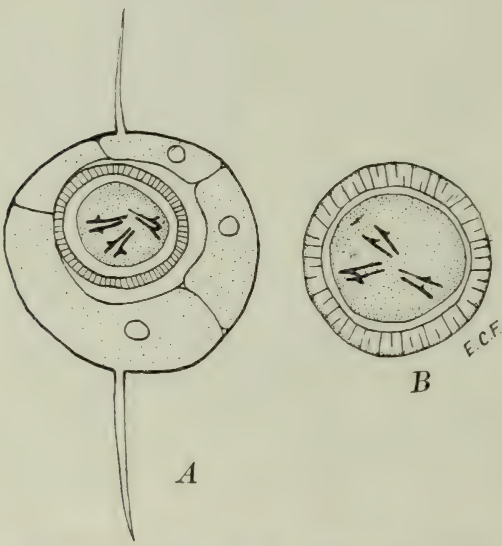


FIG. 163.—Egg of *Tænia saginata*. *A*, egg within embryonic membrane, × 383. *B*, egg freed of embryonic membrane, as seen in human feces, × 666. (Original.)

having a shell perforated with minute capillary channels and the hexacanth embryo within (Fig. 163 *B*). These eggs measure 30 to 40 by 20 to 30 μ in greater and lesser diameters. The eggs in gravid segments as well as those set free are capable of immediate development within the ox. After introduction into the intestine of this, the usual intermediate host, the shell is digested off, and the hexacanth embryo is set free, whereupon it penetrates through the gut wall into the lymphatics or bloodvessels, settling down most commonly in the pterygoid muscles, tenderloin, and wall of the heart, where it develops into the bladderworm or *Cysticercus bovis* (Fig. 164). This larva is an ovoid milky-white object, frequently possessing an opalescent translucency, and measuring 7.5 to 10 mm.

in breadth by 4 to 6 mm. in length. Within the bladder is an invaginated head which possesses in miniature the characteristics of the adult scolex.

Apparently kids and sheep have been experimentally infected with *Tænia saginata* eggs. The buffalo, giraffe and llama are recorded as natural hosts. Cases of cysticercosis bovis in man have been reported but all of the diagnoses are open to question except that of Fontan (1919), who described *Cysticercus bovis* from the mammary gland of a patient also harboring the adult worm.

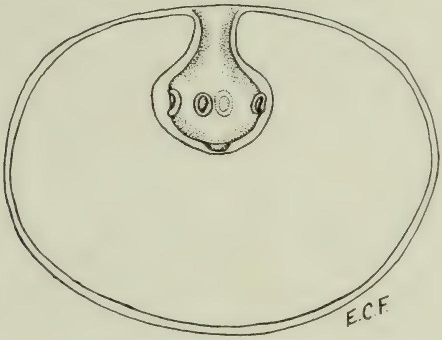


FIG. 164.—*Cysticercus bovis.* Greatly enlarged. (Original.)

Tænia saginata is the most common human tapeworm. Its incidence is several fold higher than that of *T. solium* in France, Switzerland, Denmark and Italy. In Mohammedan countries it is common while *T. solium* is practically unknown. In the Far East it is by far the more prevalent species.

Pathogenicity and Symptomatology.—The adult *Tænia saginata* produces a clinical picture similar to *T. solium.*

Diagnosis.—This is based on the recovery of gravid proglottids with lateral uterine arms numbering more than fifteen (Fig. 126, *1*) as contrasted with the smaller number in *T. solium.* If the eggs recovered from the stool are still enclosed in the mother embryonic membrane with the characteristic polar filaments, specific diagnosis can also be made.

Therapeusis.—*Filix-mas,* as indicated for *Diphyllobothrium latum.*

Prognosis.—Good. Complete eradication of the worm requires the evacuation of the head as well as the remainder of the worm, since an attached head will produce another complete worm of several meters length in three months or less.

Prophylaxis.—All beef consumed by man should be carefully inspected for cysticerci. Cattle which have not been exposed to infection for a year or more are usually safe for consumption since any previously acquired cysticerci will have calcified or caseated

during that time. Thorough cooking of beef insures complete safety. In order to extermine tæniasis saginata from an endemic area cattle should not be allowed to graze near ground polluted with human night-soil.

11. **Tænia confusa** Ward, 1896.

Synonym.—*Tænia bremneri* Stephens, 1909.

This species of *Tænia* of the subgenus *Tæniarhynchus* has been recorded three times from man in the United States, twice from Nebraska and once from Texas. The author reports herewith another complete worm from a Louisiana patient. An incomplete specimen of *Tænia*, which came from a woman in Northern Nigeria and has been described by Stephens as *T. bremneri*, is probably

FIG. 165.—Head of *Tænia confusa*. × 21. (Original.)

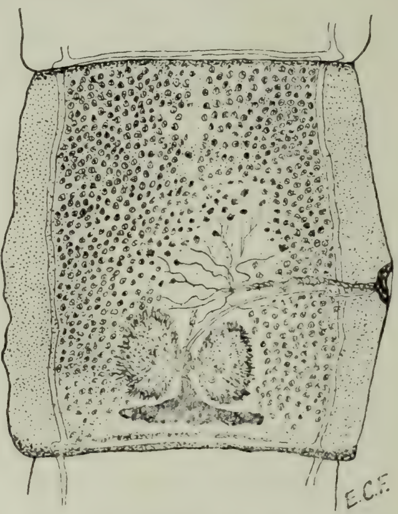


FIG. 166.—Mature proglottid of *Tænia confusa*. × 4. (After Chandler, Journal of Parasitology.)

referable to *T. confusa*. The worm has not been recorded from other hosts and its life history is unknown.

The entire worm measures from 5 to 8 meters in length and consists of from 500 to 800 proglottids. The majority of these are longer than broad and the terminal ones are unusually long and narrow (Fig. 126, *4*). The head, which is unarmed (Fig. 165) is dome-shaped and measures about 1.5 by 1.0 mm. It possesses four very muscular suckers, is unarmed, and is sharply set off from the neck region. The segments do not have the sexual organs fully developed (Fig. 166) until they are approximately squarish (9 by 9 mm.). These organs vary considerably in size in the four series studied. The terminal (*i. e.*, gravid) segments measure from 25 to

33 mm. in length by 3.5 to 9 mm. in width. The genital pore is characterized by having a plug-like papilla which nearly fills the atrium. Both cirral organ and vagina open at the tip of the plug. The gravid uterus is distinguished by the great irregularity of the divisions of the lateral arms, which are deeply constricted near their origins but are swollen toward their blind ends. The uterine eggs measure 33 by 42 μ and possess distinct polar filaments like those of *T. saginata*.

The clinical aspects of this infection have not been carefully studied, although the author's case suffered from abdominal discomfort.

12. **Tænia africana** Linstow, 1900.

Two specimens of this species of tæniarhynchid cestode were obtained by Fülleborn from a native soldier in the vicinity of Nyassa Lake, East Africa. The specimens measured 1.3 meters in length, all of the segments being broader than long. The scolex, which is unarmed and possesses a small apical sucker in addition to the usual four suctorial pockets, measures 0.63 mm. in diameter and is smaller than the short neck to which it is attached. The proglottids number about 600; the terminal gravid ones measuring about 7 mm. in length by 12 to 15 mm. in breadth. The genital pores alternate regularly in the mid-lateral line. The cirrus pouch is pyriform and thick-walled and both cirral organ and vagina are beset with ciliary bristles. The vas deferens is highly convoluted. The testes are very numerous and occupy the greater portion of the mesenchyma. The large bilobed ovary consists of unbranched club-shaped arms. The vitellaria constitute a broad narrow gland at the posterior margin of the segment. The oötype lies in the midline between the ovary and the vitellaria. The uterus in the gravid proglottids (Fig. 133, *3*) consists of a median longitudinal tube with unbranched lateral arms radiating from it. The life history and clinical aspects of this infection are undescribed.

Genus Multiceps Goeze, 1782.
(genus from *multus*, many, and *caput*, head).

13. **Multiceps multiceps** (Leske, 1780) Hall, 1910.[1]

Synonyms.—*Tænia multiceps* Leske, 1780; *Vermis vesicularis socialis* Bloch, 1780; *Tænia vesicularis cerebrina* Goeze, 1782; *Hydatigena cerebralis* Batsch, 1786; *Polycephalus ovinus* Zeder, 1803; *Cœnurus cerebralis* (Batsch, 1786) Rud., 1808; *Tænia cœnurus* Küchenmeister, 1854.

The adult stage of this tæniid cestode, like that of *Tænia solium*, is characterized by having an armature of hooklets crowning the rostellum. The complete worm measures 40 to 60 cm. in length,

[1] The related species, *M. serialis* (Gervais, 1847), which utilizes dogs for its definitive stage and hares for its cœnurus stage, is not known to be a human parasite.

possesses a pyriform head, measuring 0.8 mm. in diameter, and has a double corona of 22 to 32 hooklets, of which the large ones have a length measurement of 150 to 170 μ and the smallest ones 90 to 130 μ. The ripe proglottids have a length of 8 to 10 mm. and a breadth of 3 to 4 mm. The gravid uterus consists of a moderately long median stem and from 18 to 26 slightly ramified arms on either side. The eggs average 31 to 36 μ in diameter. The adult worm lives in the small intestine of the dog, which is the only authenticated host of this stage of the parasite, although the wolf may also serve in this capacity.

FIG. 167.—*Cœnurus cerebralis.* Cyst from brain of sheep. × $\frac{2}{5}$. (After Hall, U. S. Department of Agriculture.)

The life history of *Multiceps multiceps* was first demonstrated by Küchenmeister in 1853. The gravid proglottids or the liberated embryonated eggs are passed in the dog's feces. If the eggs are washed into puddles from which sheep or other grazing animals drink, or are splashed upon grass which they eat, they are taken into the digestive tract of the animal, the hard shell is digested away, and the hexacanth embryo escapes. It then bores a passage through the intestinal wall into the bloodvessels or lymph channels. Upon coming to a place of lodgment it may proceed to develop or it may begin an active migration for a while. Only those larvæ which reach the brain or spinal cord are able to effect complete development. Once arrived in this location the larva becomes transformed into a cœnurus, a type of bladderworm (Figs. 167, 127, *4b*) which differs from a cysticercus in having multiple heads projecting from the inner wall into the bladder cavity. As many as 100 of these scolices may develop within a single cœnurus. Each scolex (Fig. 168) is a miniature replica of the head of the adult worm and

under favorable conditions is capable of producing a complete worm. Ordinarily such opportunity is afforded when sheep or cattle dogs consume the brains of animals that have died of the bladderworm infection. The common larval hosts are sheep and goats; chamoix, cattle, horses, gazelles, antelopes and other herbivores have also been recorded as intermediate hosts. The only authentic human case was a Paris locksmith (1911), with a history of aphasia and epilepsy. *Post-mortem* search revealed the presence of a degenerate cœnurus (with free hooklets, a complete scolex and numerous calcic granules) in a lateral ventricle of the brain, while imbedded in the substance of the cerebrum was a complete cœnurus with no less than 75 scolices. It was inferred that the infection had resulted from contamination with eggs of the adult worm in dog's feces.

FIG. 168.—*Cœnurus cerebralis.* Head dissected from wall of cœnurus, greatly enlarged. (After Hall, U. S. Department of Agriculture.)

Pathogenicity and Symptomatology.—The adult stage of *Multiceps multiceps* in the dog's intestine gives rise to no particularly significant symptoms. The cœnurus in reservoir hosts produces "gid" or vertigo, due to the growth of the cœnurus in the brain and spinal cord. The single human case developed aphasia, alexia, inability to write or calculate, and frequent epileptiform seizures. These symptoms were attributed to an intracerebral parasite, the diagnosis having been later confirmed by autopsy.

Diagnosis.—This can be made only tentatively during life and requires *post-mortem* confirmation. The parasite must be differentiated from the more frequent *Cysticercus cellulosæ* and hydatid cysts of the brain, brain tumors and other cerebral lesions.

Prognosis.—Grave.

Therapeusis.—No treatment is possible except symptomatic care of the patient.

Prophylaxis.—Extreme care should be exercised in infected areas to prevent contamination from dog feces. When epidemics in sheep or other reservoir hosts break out the carcasses should be burned to prevent infection on a large scale in dogs.

14. **Multiceps glomeratus** Railliet and Henry, 1915.

Synonyms.—*Cœnurus glomeratus* (Railliet and Henry, 1915) Turner and Leiper, 1919; *Tœnia glomerata* (Railliet and Henry, 1915) Brumpt, 1922.

This species of *Multiceps* is known only in the polycephalous larval stage, which was originally described by Railliet and Henry (1915) from the gerbille. The only recorded human case is that described by Turner and Leiper from a cyst excised from the intercostal muscle of a native of Northern Nigeria. The tumor measured 1 by 2 cm., had a very delicate transparent wall and contained about 35 invaginated buds, each containing an inverted scolex, and, in addition, a great amount of calcic granules. Each scolex was provided with a crown of 32 hooklets, 16 large (90 to 100 μ long) and 16 small (65 to 70 μ long). It is believed that the human infection was accidental, due to contamination with feces of some carnivore, possibly a dog, which harbored the definitive stage.

Genus Echinococcus Rudolphi, 1801.
(genus from εχῖνος, spine, and κόκκος, berry).

15. **Echinococcus granulosus** (Batsch, 1786) Rudolphi, 1805.

Synonyms.—*Tœnia visceralis socialis granulosus* Goeze, 1782; *Hydatigena granulosa* Batsch, 1786; *Polycephalus hominis* Zeder, 1803; *Polycephalus echinococcus* Zeder, 1803; *Echinococcus hominis* (Zeder, 1800) Rud., 1810; *Acephalocystis granulosa* Lænnec, 1812; *Tœnia echinococcus* (Zeder, 1803) v. Siebold, 1853; *T. echinococcus veterinorum* (Rud., 1810) Küchenmeister, 1855; *Echinococcus polymorphus* Diesing, 1850; *Tœnia nana* v. Beneden, 1858 (*nec* v. Siebold, 1852); *Echinococcifer echinococcus* Weinland, 1861; *Echinococcus hepatis* Scholler, 1862; *Echinococcus multilocularis* Leuckart, 1863; *Echinococcus alveolaris* Klemm, 1883; *Echinococcus cysticus* Huber, 1891.

Historical.—Echinococcosis or hydatid disease was clinically well known to the ancient writers on medicine. Hippocrates (460–357 B.C.), Aretæus (9–79 A.D), and Galen (130–200 A.D.) all referred specifically to the disease. However, the term "hydatid" was used by many of the ancient and medieval physicians for any tumor or swelling of a cystic character. Redi (1684), Hartmann (1685) and Tyson (1691) were apparently the first investigators to suspect the animal nature of the true hydatid cyst. Pallas (1766) suggested the similarity if not identity of the human hydatid with that of

other animals. Goeze (1782) studied the heads developing from the cyst wall, recognized them as tænoid cestodes, and differentiated them from both the cysticercus and cœnurus types of larvæ. The adult worms in the intestine of the dog were probably first discovered by Rudolphi (1808) who believed them to be young forms of *Dipylidium caninum.* Van Beneden (1850) recognized them as a separate species (*T. nana* v. Beneden, 1858). The first experiments to determine the adult stage of the echinococcus of cattle were conducted by v. Siebold (1852), who fed the larvæ to dogs and in three weeks recovered large numbers of little tapeworms from the intestinal villi. This was confirmed by Haubner, Leuckart, Küchenmeister and Nettleship. The first experiments in which echinococci derived from man were fed to dogs (Küchenmeister, Zenker and Levison) were unsuccessful, although Naunyn in Germany (1863), Krabbe and Finsen in Iceland (1863) and Thomas (1883) in Australia bred the adult worms from hydatid cysts of human origin.

The Genus Echinococcus.

The genus Echinococcus consists of typical tæniid worms of minute size, usually not over a centimeter in length, consisting of a head and 3 or 4 proglottids, of which 1 is immature, 1 or 2 are mature, and only 1 (the terminal segment) is gravid. The head is crowned with a double row of hooks. The genital pores alternate irregularly in the mid-lateral margins. The definitive hosts of members of this genus are canines and felines, while practically any mammal may serve as the intermediate host. In addition to the common member of the genus, *Echinococcus granulosus,* the following species have been described; *E. oligarthus* (Diesing, 1863) from *Felis concolor* and *F. yaguarundi; E. minimus* Cameron, 1926 from *Canis lupus* and *E. longimanubrius* Cameron, 1926 from *Lycaon capensis.* It appears likely that *Echinococcus cruzi* Brumpt and Joyeux, 1924, obtained in the larval stage from the agouti from Brazil is the hydatid form of *E. oligarthus.*

Epidemiology of Echinococcus Granulosus Infection.—*Echinococcus granulosus* is described as cosmopolitan in its distribution, but this statement requires qualification. Considering the distribution of the larval stage in both man and domestic animals it is found that its known distribution is roughly that of the sheep-, and cattle-raising regions of the world (Fig. 169). Autochthonous human cases are, however, more limited in their distribution, the areas of heavy infection being confined to Iceland, South Australia (including Tasmania) Cape Colony (S. Africa), the Argentine, Uruguay and Paraguay, Egypt and Algeria. The infection in man is quite general in Central and Northern Europe, although the incidence is not heavy. Similarly cases of unmistakable local origin are occa-

sionally found in Northern China and Mongolia, Japan, Tonkin, the Philippines, Siberia, Arabia, and the United States. Only the larval stage is found in man. The most common larval hosts are

FIG. 169.—Map showing the distribution of *Echinococcus granulosus* in man and reservoir hosts. + indicates heavy centers of human infection. (Original.)

sheep (optimum host), cattle, pigs, horses, camels and goats. The infection in its larval form has also been recorded from monkeys, the giraffe, the tapir, the cat, the leopard, the squirrel and the rabbit. The dog, the wolf, the jackal and the domestic cat are the only proven definitive hosts. The dog incurs the infection from consuming the offal of the infected intermediate hosts, while man and other intermediate hosts acquire the infection from ingesting the eggs of the parasite through contamination with feces of infected dogs.

Statistics for Iceland show an incidence of from 4 to 16 per cent infection with hydatid in the human population, and 28 per cent infection with the adult worm in dogs. In Southern Australia, where 40 to 50 per cent of the dogs harbor the adult worm, the human population in certain districts is infected with the hydatid up to 2 per cent. The most heavily infected district in Europe appears to be that of Upper Pomerania, where 37 to 64 per cent of the cattle, 27 to 51 per cent of the sheep and 4.9 to 12.8 per cent of the pigs are infected and where 0.07 to 0.08 per cent of the human population suffers from the disease.

The Adult Worm.—The adult worm, *Echinococcus granulosus* (Fig. 170), is a minute cestode measuring from 3 to 6 mm. in length. The head is pyriform and has a transverse diameter not over 300 μ. The anteriorly situated rostellum is armed with a double crown of 28 to 50 hooklets. The four oval suckers measure about 130 μ in diameter. The neck is attenuated posterior to the suckers, so that the most constricted region is just in front of the first segment. This proglottid is immature and is usually somewhat longer than broad. The second segment is nearly twice as long as the first and contains a full complement of genital organs. The third (usually the terminal) segment is gravid; it is much broader than the second and may attain a length of 2 mm. The important organs of the mature segment are shown in Fig. 171. In the gravid proglottids the main stem of the uterus comes to possess lateral evaginations, so that its appearance is that of a loosely twisted coil. When the uterine wall become fully distended, it bursts open, allowing the discharge of the eggs. This may take place before or after the proglottid has become separated from the worm.

Development of the Hydatid.—The elucidation of most of the hydatid stage of the life cycle of *Echinococcus* has resulted from the researches of Dévè and of Dew. The egg (Fig. 172) which is evacuated in the dog's stool is so similar to that of other tæniid ova that it cannot be distinguished from them. It possesses a thick chitinous shell, perforated with minute radial pores (the outer embryonic membrane having been digested off in the dog's intestine), within which is the hexacanth embryo, characterized by three pairs of hooklets. The egg, upon being swallowed by man or other intermediate hosts as a contamination, passes into the duodenum,

where the shell is digested away and the embryo, by means of its hooklets attaches itself to the intestinal mucosa, penetrating the wall until it reaches a capillary or mesenteric venule, whereupon it is carried passively in the blood stream until it lodges in some capillary filter. Meanwhile the hooklets have been lost. The first

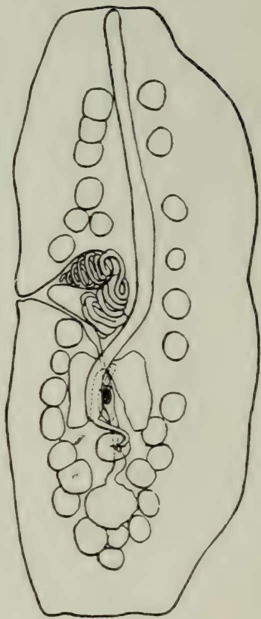


Fig. 171

Fig. 170

Fig. 172

Fig. 170.—*Echinococcus granulosus.* Entire strobila. × 40. (Original photograph from infected Peking dog.)

Fig. 171.—*Echinococcus granulosus.* Mature proglottid, greatly enlarged. (After von Erlanger, in Hall.)

Fig. 172.—Egg of *Echinococcus granulosus.* × 666. (Original.)

filter is that in the liver, where the largest proportion of the embryos lodge and become implanted. This accounts for the great preponderance of hydatid cysts of the liver. The next filter is that in the lungs, where a somewhat smaller number of embryos becomes lodged. Still smaller numbers reach more distant foci and start their development in such localities. Thus within three or four hours after being

swallowed the embryo may reach the place of its larval development. It is soon attacked by mononuclear leukocytes which probably destroy large numbers of the invaders. The surviving embryos increase rapidly in size, so that by the fourth day they reach a diameter of 40 μ and begin to vacuolate. From three to ten days later a miniature hydatid has been formed, with an inner nucleated germinal layer and an outer hyaline one. By the end of the third week, when the larva has attained a diameter of 250 μ, the host-tissue cells begin to show a definite reaction to the parasite. Immediately surrounding the hydatid the endothelial cells are arranged

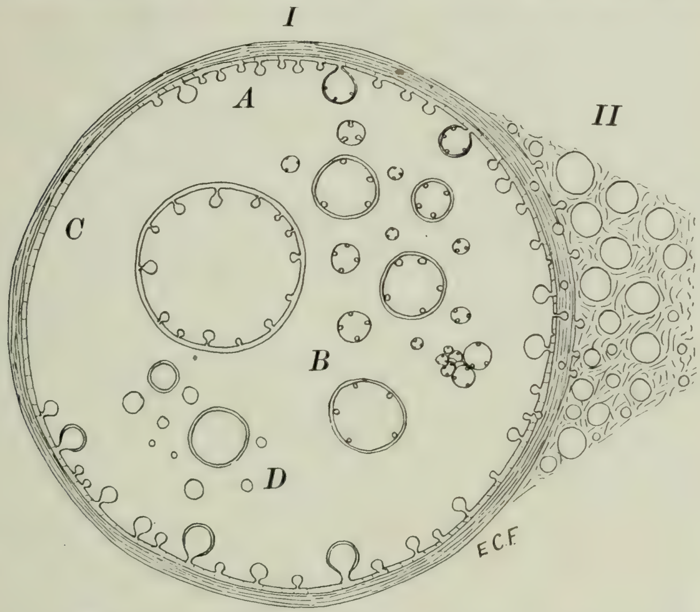
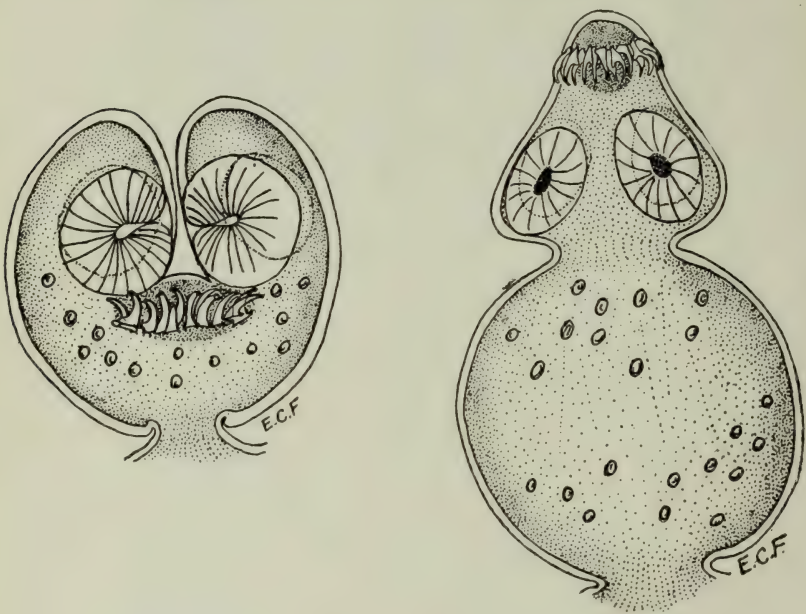


FIG. 173.—Schematic representation of the development of hydatid cyst, daughter cysts, brood capsules and scolices. I. Endogenous budding (unilocular type). *A*, brood capsule production from germinative layer; *B*, free daughter cysts producing scolices; *C*, sterile germinative layer; *D*, sterile daugher cysts. II. Exogenous budding (multilocular type). (Original.)

radially with an intercellular infiltration of giant cells and eosinophils. Surrounding this is a zone of fibroblasts, eosinophils and new bloodvessels in process of development. Fibrous tissue surrounds this zone and grades off into normal tissue cells, which may be already undergoing pressure atrophy due to the steady increase in size of the hydatid and to the development of adventitious tissue. About the fifth month, when the cyst has reached a centimeter in diameter the outer cuticular layer has become definitely laminated while the inner germinal layer is ready to produce brood capsules. These arise from a proliferation of the nuclear masses, which grow *en masse* and become vacuolated, thus forming a minute inner one-

layered cyst or vesicle, which ultimately becomes stalked. Such vesicles or brood capsules develop at many points on the germinal layer (Fig. 173). Due to trauma the brood capsules frequently become separated from their mother cyst wall and come to lie free in the fluid of the cystic cavity. Usually these brood capsules develop internal buds, which produce an internal cuticular layer. The cyst wall then forms an invagination, in which the scolex continues its development, becomes stalked, and develops suckers and hooklets (Fig. 174). Meanwhile the scolex has invaginated into its own body in order to protect its hooklets from injury. The free



A *B*

FIG. 174.—Scolex of hydatid cyst. *A*, invaginated in cyst membrane; *B*, with evaginated hooklets and suckers. × 400. (Original.)

brood capsule and free scolices in the cavity of the hydatid cyst are commonly referred to as "*hydatid sand*." In some cases the hydatid may never produce brood capsules; in other instances these may become sterilized by calcification. Likewise the brood capsules may fail to produce scolices, in which case they are *acephalocysts*. Again, daughter cysts may be produced by trauma, but their production is not a normal procedure and probably never occurs endogenously. Where they do develop, due to rupture of the primary (mother) cyst wall or to unfavorable environmental conditions for the parasite, they usually become heterotrophic, *i. e.*, they become implanted outside of their original focus of implantation.

Such cysts may originate (1) by separation of a portion of the germinal layer from the primary cyst wall, (2) from the cells of the germinative layer of the brood capsule, and (3) directly from scolices. The laminated outer layer of the hydatid is sterile and never gives rise either to endogenous or exogenous secondary cysts. Dew's explanation of the development of the exogenous cysts is that the process occurs as a herniation of both germinative and cuticular layers of the primary cyst wall through weak regions of the enveloping adventitious host-tissue layers. These herniated portions become separated from the parent cyst and develop independently.

The type of hydatid thus far described is usually referred to as *unilocular* or *univesicular*. Other varieties are not uncommon. The most frequent abnormal forms are the *multilocular* or *multivesicular* and the *osseous hydatid*.

Multilocular or Alveolar Hydatid in Man.—Ever since Virchow in 1855 described a multilocular hydatid infection of the human liver there has been considerable controversy as to its origin. One school holds that the parasite causing the infection belongs to a different species or, at least, a different variety from that producing the unilocular hydatid. Another group maintains that its form is due to the type of habitat in which the embryo becomes originally implanted, not permitting the development of the unilocular variety. Certain it is that both the structure and character of the multilocular type are markedly different from the unilocular type. It is a malignant metastasizing tumor, with an irregular reticulate outline not definitely delimited from host tissue, as contrasted with the definitely circumscribed spherical unilocular variety, usually of a benign character. Structurally (Fig. 175) it is a porous, spongy mass, consisting of multiple hydatid vesicles, none larger than a pear, frequently sterile or undergoing degeneration or calcification; imbedded in a fibrous stroma. No matter in what tissue it becomes implanted or where its satellites develop the character and nature of the alveolar type are always the same. There is never free cystic fluid, merely a jelly-like matrix. It tends to grow superficially and to become necrotic in the center due to elaboration of hydatid toxins. This type is most common in Southern Germany, Switzerland and the Tyrol, Russian and Siberia, but it has also been seen in Northern Germany, Italy, France, Japan and Argentina. Human alveolar hydatid differs morphologically from the bovine type in several important particulars, including the relatively limited character of the latter, without metastasizing elements.

Osseous Hydatid.—This is essentially a simple unilocular cyst which is not permitted to assume its usually spherical character because of confinement by the dense surrounding osseous tissues. It travels as a naked protoplast along the bony canals, its contact with the osseous tissue frequently eroding the latter. The parasite is usually sterile but may produce scolices and even endogenous

daughter cysts in case it reaches open spaces. Cuticle-formation is irregular and excessive. Exogenous cysts develop by herniation.

Dew has attempted to explain the several varieties or types of hydatid cysts on the basis of the relative development of the four

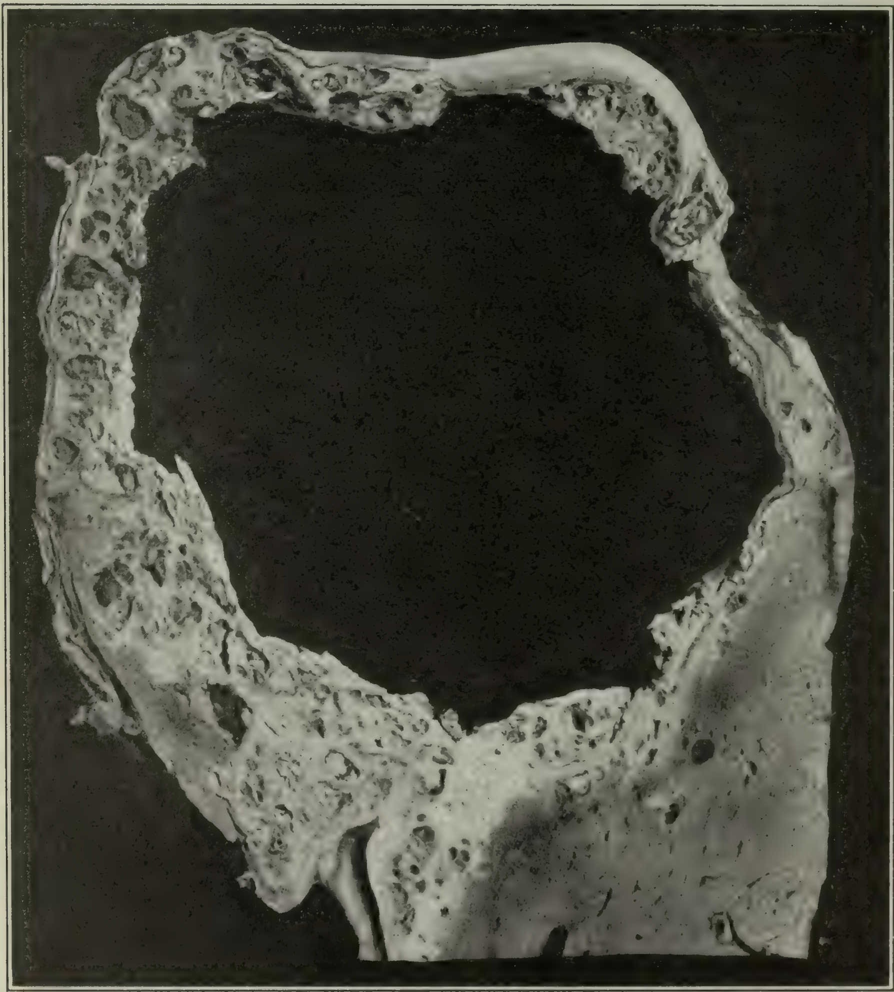


FIG. 175.—Alveolar hydatid cyst of human liver. Natural size. (Original photograph of material from Switzerland.)

functions of the germinative layer, namely, growth, budding of new reproductive elements, elaboration of hydatid fluid and production of cuticle. In unilocular hydatids all four functions proceed synchronously. In alveolar hydatid the growth function becomes exaggerated, giving rise to metastasizing roots. Thus this variety is believed

to represent a "functional dissociation of the properties of the germinal material."

Pathogenicity and Symptomatology of Hydatid Cyst.—The seriousness of hydatid cyst depends on the nature of the tumor, whether unilocular or alveolar, and on the organs or tissues in which the echinococcus embryo becomes implanted. If the embryo settles in an optimum habitat it develops normally into a unilocular cyst, with the proper balance of its functions, resulting in the production of brood capsules, scolices and the elaboration of hydatid fluid filling the cystic cavity. An inflammatory reaction sets up in the surrounding host cells, tending to the development of a fibrous tissue adventitia more or less successfully insulating the parasite from living host cells. Under such conditions the hydatid toxin is localized, as demonstrated by the infiltration of eosinophils in the immediate area around the cyst. Only where seepage of the hydatid toxin occurs through incomplete cuticulization, inclusion of bloodvessels, biliary or bronchial capillaries, does the toxin get into the general circulation, in which cases generalized eosinophilia may be expected. Unfavorable conditions for the completely encapsulated unilocular cyst result in its sterilization or the production of endogenous daughter cysts. Rupture of a fertile cyst may result in the dislodgment of germinative tissue and the development of daughter cysts exogenously. If the echinococcus embryo has become implanted into closely confined quarters, such as canalicula of the bones, it is unable to proceed to typical cyst formation but permeates all available spaces, eroding and weakening the adjacent osseous tissue. Only in case it escapes from its cramped confines is it able to proceed to normal cyst formation. The tremendous size to which abdominally implanted hydatid cysts frequently develop gives rise to increased discomfort as the cyst grows. In case it is surrounded by distensible host tissue, the latter frequently becomes modified from pressure atrophy. The implantation of echinococcus embryos in the brain or orbit produces grave symptoms, the increased dysfunction frequently resulting in sudden death.

The alveolar hydatid is a malignant tumor without circumscribed boundaries and with a tendency to send out multiple metastasizing roots into the adjacent host tissue. The brood capsules tend to form throughout the entire spongy mass and the hydatid fluid becomes diffused throughout the tissue. As growth proceeds peripherally the central area becomes insufficiently nourished and necrosis sets in, frequently resulting in a central cavity (Fig. 175). Where the metastases invade the lymphatics or bloodvessels elements of the parasite may be broken off and be carried to distant foci, there to set up new centers of growth.

While infection in endemic areas is frequently contracted during childhood, the type is usually benign and symptoms do not appear until later in life, *i. e.*, when the cyst has reached appreciable pro-

portions. However, echinococcus disease of the head, brain and orbit is subject to diagnosis in early life, due to the grave mechanical obstruction produced. The infection when contracted later in life more commonly develops into the malignant type.

Secondary infections may enter the hydatid cyst through the bloodvessels, biliary ducts or bronchioles and sterilize the cyst or they may produce rupture of the cyst wall, causing secondary cyst formation at new foci of implantation.

Diagnosis.—1. *Rœntgenological.*—This is frequently helpful in hydatid cysts of the lungs and at times where the long bones are involved.

2. *Hydatid Thrill.*—This is a specific diagnostic sign in hydatid of the abdominal viscera but is hard to elicit.

3. *Puncture of Cyst.*—This is a dangerous procedure, since it may result in anaphylactic shock due to escape of hydatid fluid into the system.

4. *Eosinophilia.*—Generalized eosinophilia is present in 20 to 25 per cent of diagnosed cases of echinococcus disease.

5. *Precipitin Reaction.*—Equal parts of preserved hydatid fluid and patient's serum are incubated for one hour at 37° C. Flocculation within thirty-six hours is suggestive of hydatid.

6. *Complement-fixation.*—0.4 cc. of hydatid fluid is used as antigen. Eighty to 90 per cent of cases give positive results.

7. *Intradermal Reaction.*—0.2 cc. of sterile hydatid fluid, injected intradermally, produces a wheal in fifteen to twenty minutes, with an outer erythematous zone which fades with the wheal. A delayed reaction some hours later usually follows around the site of injection. This is the most specific test known.

Therapeusis.—This consists in enucleation of the entire cyst, wherever possible. The majority of unilocular cysts are operable; alveolar cysts are usually inoperable. In the former case it is frequently impossible to separate the cyst wall satisfactorily from the adventitia. Marsupialization, either in one or two stages, is then indicated. The contents of the cystic cavity should be drained off, examination made to determine if scolices are present, and sterilization of the wall effected by washing with formalin-glycerin mixture before closure is attempted. If the cavity is infected open drainage is usually indicated. Extreme care should be taken that neither the hydatid fluid nor the brood capsules or scolices escape into the surrounding cavity, since the former may produce shock and the latter, if fertile, become implanted in new foci. Not uncommonly in pulmonary cases spontaneous evacuation of the cystic contents occurs, resulting, at times, in complete recovery.

Prognosis.—Fairly good in operable cases; grave in inoperable cases. Care not to spread the infection during operation is an essential corollary.

Prophylaxis.—Infection results from caressing infected dogs and from contact with dirt, vegetables and dishes contaminated with the eggs from dog's feces. Thorough washing of hands before eating would materially reduce the infection in human beings. Special attention in endemic areas should be paid to teaching children cleanly habits. This precaution would reduce the infection during childhood, which is the most susceptible period.

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SECTION III.

THE NEMATHELMINTHES OR ROUND-WORMS.

CHAPTER XX.

THE NEMATHELMINTHES OR ROUNDWORMS.

GENERAL CONSIDERATIONS.

The phylum **Nemathelminthes** (literally "thread worms") comprises a very large group of vermiform metazoa, a considerable proportion of which is parasitic for a part or the whole of the life cycle. These helminths are elongate-cylindrical in shape, round or pointed at both ends, bilaterally symmetrical, and possess a definite anteroposterior polarity. The splanchnic layers are separated from the somatic layers by a spacious body cavity. They are unsegmented and lack true limbs or appendages. Frequently the integument is provided with modifications in the form of spines or hooks, spicules, papillæ, plates, alæ, etc., while the region of the mouth may have special adaptations in the form of "jaws" and the genital opening of the male may be surrounded by a special bursa or integumentary envelope. None of the members of this phylum possess a closed vascular system nor is any species provided with a special respiratory apparatus. With few exceptions the **Nemathelminthes** are diecious. Development takes place by means of an incomplete metamorphosis, the larva which hatches from the egg in most cases resembling the parent except for the absence of mature sexual organs. Usually, however, several larval stages or instars may be recognized.

The two main divisions or classes of **Nemathelminthes** differ widely from one another. The **Nematoda**, to which the great majority of species belong, possess a gut but lack a proboscis. They also lack any structure comparable to the solenocyte or ciliated "flame-cell" which characterizes the excretory system of the majority of metazoan phyla. On the other hand, the **Acanthocephala** are provided with an oral proboscis but lack a gut. The excretory organs of the Acanthocephala are regarded by some investigators as possessing structures comparable to cilia.

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CHAPTER XXI.

THE NEMATHELMINTHES OR ROUNDWORMS.
(CONTINUED.)

CLASSIFICATION.

As the number of known species of nematodes has increased by leaps and bounds within the past two decades, the older system of classification, whereby family groups were loosely united under the general Class **Nematoda** Rudolphi, 1808, has become untenable. Moreover, increased information regarding the structure of the many species involved, and more especially concerning the life cycles and the larval stages of these worms, has resulted in a gradual grouping of the families into superfamilies, and these, in turn, into suborders and orders. The system which the author has adopted is in keeping with this tendency. For the most part the superfamily groupings are those of Railliet. For the more comprehensive groupings Ward's and Cram's classifications have been used. The outline of the system is as follows.

Phylum Nemathelminthes Vogt (*fide* Carus, 1863).
Unsegmented animals, bilaterally symmetrical, with three body layers; body elongate, cylindrical or filiform; alimentary tract with mouth and usually with anal opening; large body cavity; no cilia in any stage of the life cycle; sexes separate, except possibly in a few species of the Rhabdiasoidea.

CLASS I. NEMATODA RUDOLPHI, 1808, EMEND. DIESING, 1861.

Nemathelminthes with a gut but without a proboscis.

Subclass I. Eunematoda Ward, 1916.

Nematodes in which the body cavity is not lined with epithelium, the gonads being continuous with their ducts; lateral chorda present; cloaca absent in the female.

ORDER I. TRICHOSYRINGATA WARD, 1917.

Nematodes with an esophagus consisting of a narrow chitinous tube running through the center of a row of single cells.

Suborder I. Trichinellata nom. nov. (Syn. Trichurata Skrjabin, 1916).

Intestinal canal complete; anus always present, terminal; vulva anterior to mid-region of body; ovary single, originating posteriorly.

TYPE SUPERFAMILY TRICHINELLOIDEA HALL, 1916.

With the characteristics of the suborder; anterior part of body filiform; intestinal tract complete, with anal opening; male genital spicule single or absent; female with single ovary.

Family I. TRICHINELLIDÆ Ward, 1907.

Copulatory sheath and spicule absent in male; females viviparous; adults in intestine and larvæ in muscles of mammals. Human representative: *Trichinella spiralis* (Owen, 1835).

Family II. TRICHOCEPHALIDÆ Baird, 1853.

Copulatory sheath of male present, usually provided with spicule; female oviparous; eggs barrel-shaped, with clear polar plugs; adults parasitic in intestine, liver or urinary bladder of mammals and birds. Human representatives: *Trichocephalus trichiurus* (Linn., 1771); *Hepaticola hepatica* (Bancroft, 1893).

Suborder II. Mermithata nom. nov.

Posterior region of the intestine atrophied; anus vestigial or absent; body thin, thread-like, elongate; larvæ parasitic in body cavity of arthropods or snails; adults free in soil or water. Larvæ (*Agamomermis*) rarely and only accidentally present in human intestine as contamination of food or water.

ORDER II. MYOSYRINGATA WARD, 1917.

Esophagus prominent, muscular, with triradiate or tripartite lumen.

Suborder I. Rhabdiasata Cram, 1927.

Heterogamic forms, the parasitic generation consisting of females with no males or hermaphroditic individuals, the free-living generation consisting of males and females.

TYPE SUPERFAMILY RHABDIASOIDEA RAILLIET, 1916.

Heterogenetic forms; parasitic stages parthenogenetic, syngonic or hermaphroditic; bursa copulatrix not present in male; uteri of female two, divergent.

Family I. RHABDIASIDÆ Railliet, 1915.

Forms with a three-sided, prismatic or tubular buccal cavity, usually without teeth; esophagus usually with a posterior bulb containing valves, and frequently with a prebulbar swelling; include both parasitic and coprophagous species. Human representatives: *Strongyloides stercoralis* (Bavay, 1877); *Rhabditis pellio* (Schneider, 1866); *R. niellyi* (Blanchard, 1885); *R. hominis* Kobayashi, 1914; *Turbatrix aceti* (Mueller, 1783).

Family II. TYLENCHIDÆ Micoletzky, 1922. (= ANGUILLULINIDÆ Baylis and Daubney, 1926).

Small free-living, semiparasitic or parasitic species, having a pharynx in the adult modified into a protrusile spear; esophagus simple or with a median and a posterior bulb-like swelling. The adults, larvæ or eggs of those forms parasitic in vegetable tissues or saprozoic in decaying vegetation have at times been reported as parasites of the human intestinal tract, but such a condition is purely accidental. The following identified species have been reported from man: *Anguillulina putrefaciens* (Kuehn, 1879); *Heterodera radicicola* (Greef, 1872) [= "*Oxyuris incognita*" Kofoid and White, 1919].

Suborder II. Strongylata Railliet and Henry, 1913.

Bursate nematodes, the membraneous bursa supported by a system of six-paired and one or two dorsal rays; males with two spicules and females usually with two ovaries. Musculature polymyerian or meromyerian.

SUPERFAMILY I. STRONGYLOIDEA (WEINLAND, 1858) HALL, 1913.

Meromyerian; male with broad conspicuous bursa traversed with rays; copulatory spicules typically two; ovary single or double; buccal capsule usually well-developed in both sexes; rhabditiform larvæ develop in moist earth.

Family I. STRONGYLIDÆ Baird, 1853.

Bursa and two equal spicules present; buccal capsule wide, without teeth or cutting plates but with a ring of chitinous armature; usually parasitic in alimentary canal of vertebrates. Human representatives: *Ternidens deminutus* (Railliet and Henry, 1905); *Œsophagostomum apiostomum* (Willach, 1891); *Œ. stephanostomum* var. *thomasi* Railliet and Henry, 1909.

Family II. SYNGAMIDÆ Leiper, 1912.

Bursa short, spicules usually equal, stout; buccal capsule well-developed, without conspicuous teeth, but with a thickened chitinous rim; parasites of the respiratory system. Human representative: *Syngamus kingi* Leiper, 1913.

Family III. ANCYLOSTOMATIDÆ (Looss, 1905) Lane, 1917.

Bursa large, with well-developed rays; buccal capsule well-developed and armed; uteri divergent; parasites of the alimentary canal of vertebrates. Human representatives: *Ancylostoma duodenale* (Dubini, 1843); *A. caninum* (Ercolani, 1859); *A. malayanum* (Alessandrini, 1905); *A. braziliense* Gomez de Faria, 1910; *Necator americanus* (Stiles, 1902).

Superfamily II. Trichostrongyloidea Cram, 1927.

Meromyerian; buccal capsule absent or rudimentary; relatively slender forms, but with bursa not reduced in size. All species of this superfamily recorded from man belong to the

Type Family TRICHOSTRONGYLIDÆ Leiper, 1912.

Bursa large, with well-developed rays; buccal capsule absent; cutting organ, if present, consisting of a single lancet; uteri divergent; parasitic in alimentary canal of ruminants. Human representatives: *Trichostrongylus colubriformis* (Giles, 1892); *T. probolurus* (Rail., 1896); *T. vitrinus* Looss, 1905; *T. orientalis* Jimbo, 1914; *Hæmonchus contortus* (Rud., 1803); *Mecistocirrus digitatus* (v. Linst., 1906).

Superfamily III. Metastrongyloidea Cram, 1927.

Polymerian; bursa with true but rather stunted rays; buccal capsule absent or only slightly developed; mouth simple, directed straight forward; uteri convergent; parasitic in respiratory or circulatory system or in cranial sinuses of mammals.

Type Family METASTRONGYLIDÆ Leiper, 1908.

With the characters of the superfamily. Human representative: *Metastrongylus apri* (Gmelin, 1790).

Suborder III. Oxyurata Cram, 1927.

Meromyerian; males with one spicule (exceptionally two), imperfectly chitinized; females oviparous; eggs flattened on one side; forms monoxenous.

Type Superfamily Oxyuroidea Railliet, 1916.

Small nematodes, pin-shaped, with buccal capsule; males without a true bursa or with a poorly-developed one, but with a posterior papilla or caudal projection; copulatory spicules one or two; ovaries one or two; females oviparous; eggs few, flat on one side; parasitic in cecum of vertebrates.

Type Family OXYURIDÆ Cobbold, 1864.

With the characteristics of the superfamily; male with a single spicule or two equal spicules. Human representatives: *Enterobius vermicularis* (Linn., 1758): *Syphacia obvelata* (Rud., 1802).

Suborder IV. Ascaridata Railliet and Henry, 1915.

Polymerian; mouth typically with three lips; buccal capsule absent; males with one or two spicules; females usually with two ovaries, occasionally more than two; oviparous; forms usually monoxenous, but at times complicated by a larval migration through the body of the host.

Type Superfamily Ascaroidea Railliet and Henry, 1915.

Usually fairly large or stout nematodes; mouth commonly provided with three lips but without buccal capsule; males usually without caudal alæ, with one or two copulatory spicules; females with two ovaries, oviparous; development direct, usually without an intermediate host.

Type Family ASCARIDÆ Baird, 1853.

Male with two spicules; uterine branches parallel; eggs very numerous, unsegmented when laid. Human representatives: *Ascaris lumbricoides* Linn., 1758; *Toxocara canis* (Werner, 1782); *Belascaris cati* (Schrank, 1788); *Lagochilascaris minor* Leiper, 1909.

Suborder V. Spirurata Railliet and Henry, 1915.

Body usually long and slender; mouth fundamentally with two lips or without lips and surrounded by papillæ or other oral structures; esophagus slender, without posterior bulb; male with one or two spicules, with or without papillæ or alæ; female larger than male; vulva present or absent; two, four or more uteri, rarely one; heteroxenous, larvæ in intermediate hosts.

Superfamily I. Spiruroidea Railliet and Henry, 1915.

Filariform or fairly stout worms; mouth without lips or with two or more lips which bound the buccal cavity; esophagus divided into

a short anterior muscular and a long posterior glandular part; intestine simple, without diverticula; caudal alæ usually present in male; spicules two, frequently unequal; vulva usually near the middle of the body; parasites of the alimentary tract, respiratory system, or orbital, nasal or oral cavities of vertebrates.

Family I. SPIRURIDÆ Oerley, 1885.

Mouth usually with two or four trilobed lateral lips, occasionally accessory dorsal and ventral lips; chitinized vestibule in front of esophagus; caudal alæ of male well-developed, supported by pedunculated papillæ; vulva of female near the middle of the body; oviparous; parasitic in the tissues of the mouth, esophagus, stomach, and intestine of vertebrates. Human representative: *Gongylonema pulchrum* Molin, 1857 (= *G. subtile* Alessandrini, 1914; also *G. hominis* Stiles, 1921).

Family II. GNATHOSTOMATIDÆ Blanchard, 1895.

Mouth with two large, trilobed lips; whole or anterior part of body covered with minute ramified spines; male with caudal alæ supported by broad pedunculated papillæ; copulatory spicules equal or unequal; female with vulva posterior to middle of body; uterine tubes two or four; oviparous; eggs with thin shells, with external pitting; parasitic in wall of intestine of fishes, reptiles and mammals. Human representatives: *Gnathostoma spinigerum* Owen, 1836; *G. hispidum* Fetsch., 1872.

Family III. PHYSALOPTERIDÆ Leiper, 1908.

Mouth with two large, simple, triangular lips, armed internally with one or more teeth; cuticle reflected forward over the lips to form a cephalic collarette; bursal alæ with supporting papillæ in form of lanceolate expansion; caudal papillæ pedunculated; parasitic in alimentary canal of vertebrates. Human representative: *Physaloptera caucasica* v. Linstow, 1902.

Family IV. THELAZIIDÆ Railliet, 1916.

Mouth without definite lips or with inconspicuous lips; short buccal capsule usually present; caudal extremity of male with or without alæ, typically with numerous preanal papillæ; vulva of female anterior or posterior; ovoviviparous; parasitic in orbital, nasal or oral cavities of mammals or birds, in the air-sacs of birds, or the intestine of fishes. Human representative: *Thelazia callipæda* Railliet and Henry, 1910.

Superfamily II. Dioctophymoidea Railliet, 1916.

Medium- to large-sized nematodes; males with a bell-shaped muscular bursa, unsupported by rays, with a single copulatory spicule; female with single ovary; eggs with thickened shells, lighter at the poles and with depressed sculpturing on the surface; in lumen of kidney and abdominal cavity of mammals.

Type Family DIOCTOPHYMIDÆ Railliet, 1915.

With the characteristics of the superfamily. Human representative: *Dioctophyme renale* (Goeze, 1782).

Superfamily III. Filarioidea Weinland, 1858.

Filiform worms; mouth usually simple, without conspicuous lips, buccal cavity absent or rudimentary; esophagus cylindrical, frequently divided into two parts; intestine simple, sometimes atrophied posteriorly; males with or without caudal alæ; copulatory spicules usually unequal and dissimilar; vulva of female almost always in esophageal region; parasitic in the circulatory, lymphatic, muscular, or connective tissues, or in serous cavities of vertebrates.

Family I. FILARIIDÆ (Cobbold, 1864) Claus, 1885.

Females not more than three or four times as long as males; anus present; esophagus without bulb; males with or without alæ; vulva of females in region of esophagus; oviparous, ovoviviparous or viviparous; parasitic in tissues of body.

Subfamily I. Filariinæ Stiles, 1907.—Cuticle smooth or transversely striated; mouth simple or with two minute lateral lips, not bounded by chitinous peribuccal rings or epaulette-like structures; without trident-like chitinous structures on each side of anterior end of esophagus; spicules unequal and dissimilar; vulva in esophageal region or just posterior to it; larval stages in mosquitoes. Human representatives: *Wuchereria bancrofti* (Cobbold, 1877); *Dirofilaria magalhæsi* (Blanchard, 1896).

Subfamily II. Onchocercinæ Leiper, 1911.—Cuticle without bosses in either sex, reinforced by external or internal annular thickenings; mouth simple, without chitinous peribuccal ring or lateral epaulette-like structures; without trident-like chitinous structures on each side of anterior end of esophagus; spicules of male unequal; vulva of female in esophageal region; larvæ in blood-sucking flies (Simulium). Human representatives: *Onchocerca volvulus* (Leuckart, 1893); *O. caecutiens* Brumpt, 1919.

Subfamily III. Loainæ Yorke and Maplestone, 1926.—Cuticle with bossing in both sexes; mouth simple, without chitinous peribuccal

ring or lateral epaulette-like structures; without trident-like chitinous structures on each side of the anterior end of esophagus; spicules of male equal or unequal; vulva of female in esophageal region or slightly posterior to it; parasitic in mammals and birds; larval stages in Chrysops and possibly other blood-sucking flies. Human representative: *Loa loa* (Cobbold, 1864).

Subfamily IV. Setariinæ Yorke and Maplestone, 1926, emend.—Cuticle smooth or bossed; mouth surrounded by a peribuccal chitinous ring, or bounded by lateral epaulette-like structures or by small spinous teeth; spicules of male unequal; caudal extremity of female provided with a pair of lateral appendages; vulva in the esophageal region; parasitic in tissues and body cavity of amphibians, reptiles, birds, and mammals. Various blood-sucking arthropods serve as intermediate hosts for the larvæ. Human representatives: *Acanthocheilonema perstans* (Manson, 1891); *Mansonella ozzardi* (Manson, 1897).

Family II. FUELLEBORNIIDÆ nom. nov.

Females enormously longer than males; anus and vulva atrophied in gravid females, which discharge their embryos through a rupture of the body-wall near the mouth; viviparous; parasitic in connective tissue and body cavities of vertebrates. Human representative: *Fuellebornius medinensis* (Linn., 1758).

Subclass II. Gordiacea v. Siebold, 1848 (*Fide* Carus, 1863).

Nematodes in which the body cavity is lined by epithelium; gonads not continuous with their ducts, the ova being discharged into the body cavity and then passed into the ducts; alimentary canal atrophied in sexually mature worms; lateral chorda absent; cloaca present in female. These are the "hairworms," commonly found as adults in bodies of fresh-water, with larval stage in insects; their presence in the intestinal tract of man is purely accidental.

CLASS II. ACANTHOCEPHALA RUDOLPHI, 1808.

Diecious, thorny-headed worms, with a proboscis armed with spines and without an intestinal tract; embryos spinose; larvæ in intermediate host; adults in intestine of vertebrates.

ORDER I. NEOECHINORHYNCHATA nom. nov. (pro Suborder NEOECHINORHYNCHIDEA SOUTHWELL AND MACFIE, 1925.)

Proboscis usually short and subspherical; proboscis sheath (when present) a tube with a simple wall; prostatic gland a single syncitial mass; nuclei of subcuticula and lemnisci few and very large. This order contains three families, **Neoechinorhynchidæ** Ward, 1917,

Quadrigyridæ Van Cleave, 1920 and **Apororhynchidæ** Shipley, 1900, parasitic in fishes, reptiles and birds. No representative in man or mammals.

ORDER II. GIGANTORHYNCHATA nom. nov. (pro Suborder GIGANTORHYNCHIDEA SOUTHWELL AND MACFIE, 1925).

Proboscis reduced, often composing only a small part of the proboscis-like structure; proboscis-sheath with a thick two-layered muscular wall into which the proboscis (when present) cannot be retracted, the proboscis-sheath being inserted near the anterior extremity; neck region present; prostatic glands not a single syncitial mass; nuclei of the subcuticula and lemnisci relatively small and numerous. This order contains two families, **Gigantorhynchidæ** Hamann, 1892 and **Oligacanthorhynchidæ** Southwell and Macfie, 1925, parasitic in birds and mammals. A species of the latter family, *Macracanthorhynchus hirudinaceus* (Pallas, 1881), is a cosmopolitan parasite of pigs and is reported as a parasite of the human intestine.

ORDER III. ECHINORHYNCHATA nom. nov. (pro Suborder ECHINORHYNCHIDEA SOUTHWELL AND MACFIE, 1925).

Proboscis well-developed; proboscis-sheath with double walls (except in the genus *Mediorhynchus*) into which the proboscis can be retracted; prostatic glands not a single syncitial mass; nuclei of the subcuticula and lemnisci relatively small and numerous, or with few large dendritic nuclei. This order contains five families, **Echinorhynchidæ** Cobbold, 1879, **Rhadinorhynchidæ** Travassos, 1923, **Centrorhynchidæ** Van Cleave, 1916, **Corynosomidæ** Southwell and Macfie, 1925 and **Moniliformidæ** Van Cleave, 1924, parasitic in fishes, reptiles, birds and mammals. The type species of the genus *Moniliformis* (family **Moniliformidæ**), which is a common parasite of rodents in certain localities, has been reported as a human parasite.

IMPORTANT REFERENCES ON THE CLASSIFICATION OF NEMATODES.

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CHAPTER XXII.

THE NEMATODES OR TRUE ROUNDWORMS.

STRUCTURE AND LIFE HISTORY.

The **Nematodes** are those Nemathelminthes, which possess a gut but lack a proboscis; they are usually filariform (*e. g.*, have "thread-like bodies"), with the anterior and posterior ends more or less pointed or rounded. The male is distinguished by being smaller than the female and by usually having the posterior end of its body recurved ventrad. Except in cases where the worm ingests the blood of its host as food it is usually a creamy or ivory-yellow color. The majority of species are at least partially transparent while still alive, but fixation commonly increases their opacity. A large number of nematode species is parasitic in habits, but probably an even larger number is free-living. Many species are obligatory parasites during a part of their life cycle but have a free-living phase. Forms like *Strongyloides stercoralis*, are apparently within certain limits facultatively parasitic or free-living. The host-parasite relationship of the nematode group has the greatest latitude of any of the helminth groups. Many species are parasitic in or on vegetable tissues, including roots, stems, leaves and even seeds. A wide variety of species is endoparasitic in invertebrate tissues. By far the largest proportion of parasitic nematodes, however, are parasites of vertebrates. Of the 560 genera of nematodes recognized by Baylis and Daubney (1926) 364 are recorded as being parasitic in vertebrate hosts.

Structure of the Adult Roundworm.—The adult nematode varies in size from a filariform object just visible to the naked eye (*Trichinella*, *Strongyloides*) to a large rod-like worm (*Dioctophyme*) or an elongate wire-like worm which may attain a length of $1\frac{1}{2}$ meters (*Fuellebornius*). An extreme alteration from the primitive shape is found in *Heterodera radicicola*, a common parasite of vegetable roots, the mature female of which has become swollen like a lemon. The majority of species are probably under 1 cm. in length. They are primitively bilaterally symmetrical but their parasitic or sessile habits have tended toward the development of radial symmetry.

The somatic layers of the nematode (Fig. 176, *A*, *B*, *C*) consist of (1) an outer integumentary cuticle, which is a hardened secretion of the underlying cells; (2) an epithelial layer, or subcuticle, just beneath the integument, readily observed in young worms but so

modified in older ones or in large species as to appear to be a syncitial matrix in which fibers and nuclei intermingle; (3) and the dermo-muscular layer, which constitutes the principal somatic musculature. Arising from the subcuticular layer and projecting out into the body cavity are the four longitudinal lines, consisting of the dorsal and ventral median lines and the pair of lateral lines (Fig. 176). The muscle bands, which are made up of muscle cells with sarcoplastic processes, consist of one layer of longitudinal cells. These cells are divided into four longitudinal groups by the four longitudinal lines. In its simplest form (*i. e.*, in *Enterobius* and *Ancylostoma*) each of the four units consists in cross-section of only two cells and is called *meromyerial.* In case there are in each group numerous cells, each with its protoplasmic element projecting into the body cavity (*i. e.*, *Ascaris*, Fig. 176 *B*), the type is referred to as *polymyerial.* In *Trichocephalus* and certain other species the somatic musculature consists of a large number of muscle-cell elements closely apposed to one another so as to give the appearance of an inner casing or lining. This type is spoken of as *holomyerial.* These muscle bands by synchronous contraction cause the worm to shorten; unilateral contraction results in bending the worm to one side. There are no circular muscles antagonistic in action to the longitudinals; the elastic property of the cuticle alone serves to elongate the worm. In the **Eunematoda**, the group to which all of the true nematodes belong, the body cavity is a *schizocele*, *i. e.*, it lacks an epithelial lining such as the **Gordiacea** have.

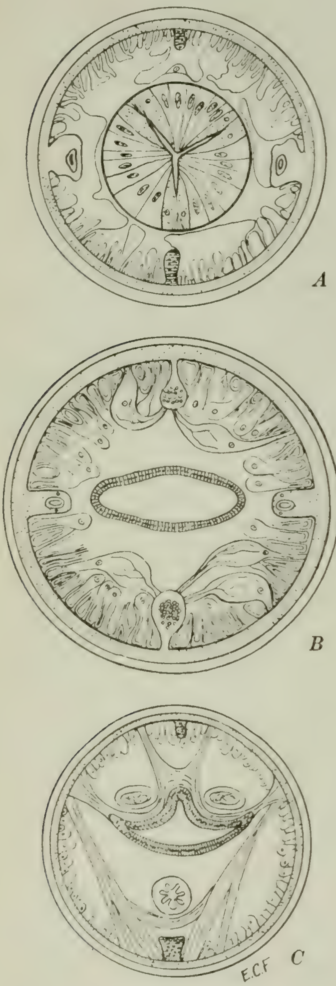

Fig. 176. — Transverse section through important regions of *Ascaris lumbricoides*. *A*, at the level of the esophagus (after Goldschmidt, in Zoölogischen Anzeiger.) *B*, through the equatorial region (after Brandes, in Fantham, Stephens and Theobold, Animal Parasites of Man, courtesy of John Bale Sons & Danielsson, Ltd.) *C*, through the posterior end, (after Leuckart, in Fantham, Stephens and Theobold, Animal Parasites of Man, John Bale Sons & Danielsson, Ltd.) × ca. 8.

The anterior end of the nematode body is modified for purposes of abrasion (*Esophagostomum*), for attachment to host tissue (*Ancylostoma, Gnathostoma*), or for special sensory purposes (*Ascaris*). To this end teeth, hooks biting or sawing plates and papillæ have been developed. Some species such as *Gnathostoma* have their entire cuticle covered with spines, but the majority of species have a glabrous integument. Bossing is a prominent feature on the cuticle of some of the filarioid nematodes. Both the anterior and posterior portions of the digestive tract are covered with a continuation of the cuticle. The oral cavity or pharynx is frequently developed into a buccal or pharyngeal pocket or capsule, which may serve as an acetabulum. The alimentary tube consists of three consecutive regions, an esophagus, a mid-gut, and a rectum. The esophagus is a very muscular organ, save in the **Trichinellata**, where it consists of a narrow tube running through a column of single cells. It has an inner chitinous lining and its internal cavity is frequently triradiate (Fig. 176*A*). Esophageal glands open into this organ. The esophagus leads posteriorly into the mid-gut, which consists of a single layer of columnar cells (Fig. 176*B*) lined with non-vibratile cilia. Strong valves, capable of completely closing the lumen, are situated at the junction of the esophagus with the mid-gut. The rectum is short and is also lined with cuticle. Anteriorly it is provided with a sphincter muscle. Posteriorly it opens outward through the anus into the cloaca. It is usually anchored to the somatic wall by oblique muscle bands (Fig. 176 *C*). The excretory system consists of two longitudinal tubules which are imbedded in the substance of the lateral lines (Fig. 176*B*); these tubules end blindly posteriad and unite anteriad along the mid-ventral line close behind the mouth, where they open through a single pore.

The nervous system (Fig. 177) consists primarily of commissures and longitudinal nerve trunks. The central organ in the system is the circumesophageal ring which completely surrounds the esophagus just in front of the excretory pore. From it there arise six short anterior trunks, innervating the head. The important posterior ventral and dorsal trunks run respectively in the ventral and dorsal median lines of the subcuticular matrix. The four lateral trunks have a double origin. The more dorsal pair arises from the circumesophageal nerve ring, while the more ventral pair arises from the ventral trunk just in front of the excretory pore. The dorsal and ventral elements on each side enter the lateral line somewhat behind the middle of the body but do not amalgamate until they reach the level of the anal ganglion. They then continue caudad, receiving first the forked elements of the ventral, then of the dorsal trunk, and finally uniting near the caudal extremity. An important circumcloacal commissure arises from the anal ganglion in the male worm. Several asymmetrical commissures from the ventral to the

dorsal trunks are found along the course of these tracts. In parasitic nematodes organs of special sense are confined to the labial and (in the male) to the genital papillæ, the former supplied by a delicate nerve terminus which pierces the cuticle, the latter by a swollen end-organ lying under the cuticle.

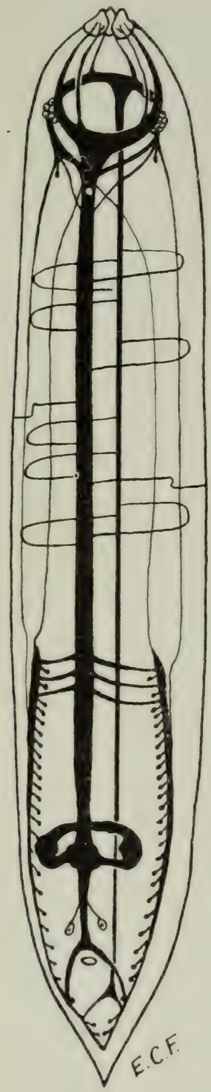

Fig. 177.—Diagram of the nervous system of a male *Ascaris*. (After Brandes.)

The nematodes are diecious, *i. e.,* males and females are separate individuals. In a few cases the male is parasitic in the body of the female. Rarely parthenogenesis or syngonesis is believed to occur (parasitic generation of *Strongyloides*). As a rule the male is considerably smaller than the female. In the male the reproductive organs consist typically of a single tube differentiated into *testis* (*t*), *vas deferens* (*vd*), *vesicula seminalis* (*sv*) and *ejaculatory duct* (*ejd*). In the simplest forms this tube constitutes a straight line; in most species, however, it is coiled and convoluted back and forth many times within the body cavity. The male reproductive system opens posteriorly near the anus (Fig. 178). The ejaculatory duct is lined with cement or *prostate glands* (*cg*). Accessory copulatory apparatus is usually highly developed. This consists of one or a pair of *copulatory* bristles or *spicules* (*sp*), regulated by a *gubernaculum* (*gub*), while the cloaca through which both intestinal (*c*)and reproductive (*ejd*) systems discharge may be guarded by a *genital cone.* In some groups there is a *bursa copulatrix* enveloping the posterior end of the male and serving as an organ of attachment to the body of the female during copulation. The spermatozoa are amœboid rather than flagellar in character. They become fully ripened only after they have been transferred to the uteri of the female.

The vulva or external genital opening of the female is thick-lipped and is usually ventral in position, varying in axial position from near the head to near the anus, but as a rule more commonly found in the anterior half of the body. In a few cases there is only a single reproductive set (*i. e., Trichocephalus*) but the great majority of species have

a paired set opening into the unpaired vulva. In its simplest form the female genitalia consist of two filiform ovaries, two tubular uteri and a vulva. In *Ancylostoma* and many other species, however, the following regions are recognized (Fig. 179): *ovary* (*ov*), *oviduct* (*od*), *receptaculum seminis* (*rs*), *uterus* (*ut*), *ovejector* (*ovj*) and *vagina* (*vg*), all paired, the two members joining to open into the unpaired *vulva* (*vu*). In species such as *Strongyloides*, where the female generative tubules are relatively broad and short, the two

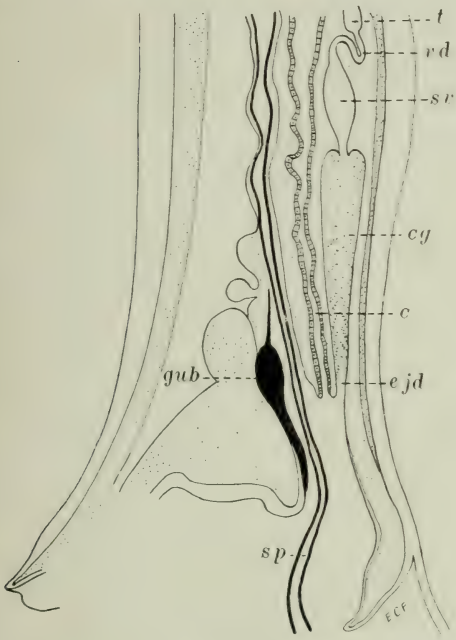

Fig. 178. — Sagittal optical section through the posterior end of a male *Ancylostoma duodenale*, showing the genital organs. (Original adaptation from Looss.)

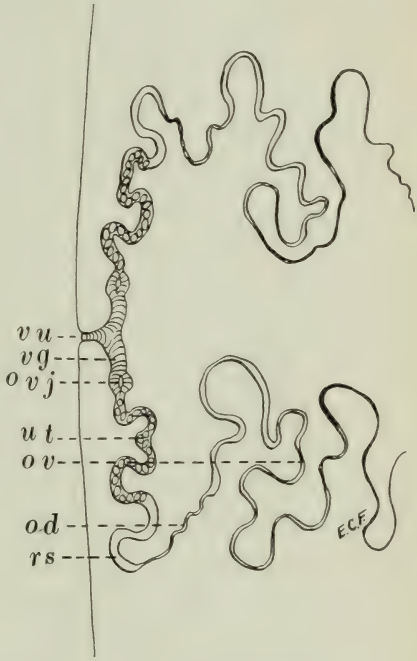

Fig. 179.—The female genitalia in *Ancylostoma duodenale*. (Original adaptation from Looss.)

branches separate from the vulva to form anterior and posterior elements. In many species, however, the total length of the tubules is several times that of the body length of the worm resulting in an involved coiling and twisting of the tubules back and forth through the body cavity. Such excessive production of the generative system may cause the intestinal tract to be displaced, or, in exceptional cases, may bring about an unusual thickening of the body.

The eggs, which are derived from a polynucleated mass of protoplasm at the inner end of the ovary, pass down the lumen of the

ovarian tubule, thence through the oviduct, and are fertilized *en route* through the receptaculum seminis on the way to the uterus. Here they are stored for a longer or shorter period, depending on the species. When the uterus becomes gravid the eggs are squeezed out through the ovejector into the vulva and are laid. The state of development at the time of oviposition varies in different groups of nematodes but is usually related to the length of time the eggs are stored *in utero*. In *Ascaris* the egg recovered in the feces of the host is usually unsegmented. In *Trichocephalus* the first cleavage frequently takes place shortly after oviposition. The hookworm egg recovered in normally formed feces is usually 2- to 4-celled. All of these species are referred to as *oviparous*. Certain other species, such as the parasitic generation of *Strongyloides stercoralis*, have embryonated eggs, with rhabditiform larvæ ready to hatch when the eggs are laid. They are said to be *ovoviviparous*. In still other species, such as *Trichinella spiralis* and *Fuellebornius medinensis*, the larvæ have hatched previous to their escape from the mother worm. Such nematodes are spoken of as *viviparous*. In certain filarioid nematodes the egg-shell elongates *in utero* to accommodate the developing larva, so that by the time the egg is laid it has become stretched into the shape of an enveloping sheath. Hatching, in the strict sense, does not occur until this embryonic "sheath" is shed. In *Thelazia callipæda*, the egg-shell, after oviposition, "balloons" on one side and serves as a float for the enclosed larva.

The Life Cycle of the Parasitic Nematodes.—The life cycles of parasitic nematodes include, on the one hand, types with a very simple development, and, on the other, those with a very complicated history, with multitudinous intermediate varieties. Probably the most simple type in a human parasite is that of *Enterobius vermicularis*, the rhabditiform larva of which has completed its development within the egg at the time of oviposition, so that the accidental ingestion of this mature egg on the part of the human host provides all the conditions necessary for the hatching and development of the larva to an adult worm in the human intestine. Eggs of *Ascaris* and *Trichocephalus* require some time outside of the digestive tract before the larva is sufficiently mature for hatching to take place in the human intestinal tract. Although hookworm and *Trichostrongylus* eggs occasionally hatch inside the intestine of the host, in both cases the emerging rhabditiform larva requires a period of growth followed by metamorphosis into a filariform larva in a free-living environment before the worm may again utilize the body of the host. *Strongyloides stercoralis* usually intercalates a complete free-living generation with its parasitic one. Furthermore, the filarioid nematodes and related forms require an arthropod intermediate host: *Wuchereria bancrofti* utilizes mosquitoes; *Fuellebornius medinensis* seeks a *Cyclops; Loa loa* and *Onchocerca volvulus*

require species of *Chrysops* and *Simulium* respectively. In the case of biting insects the freely moving larvæ are removed from the peripheral circulation or from peripheral lesions by puncturing the skin; in the case of non-biting arthropods the larvæ are ingested by the intermediate host after active or passive escape from lesions in the definitive host. Within the intermediate host a metamorphosis of the larva takes place, usually accompanied by a process of moulting, whereupon the mature larva may, in the case of biting insects be transferred actively to the definitive host by the bite of the intermediate host, or it may become quiescent, or even become encysted within an adventitious capsule and await passive transfer through the accidental ingestion of the larval host by the definitive host.

The routes of migration of some of the parasitic nematode species within the definitive host are likewise complicated and devious. *Gongylonema* larvæ, upon being swallowed, directly invade the epithelium of the anterior portion of the digestive tract and develop to maturity. Mature larvæ of *Hæmonchus,* when swallowed by the appropriate host, become attached to the wall of the stomach and proceed with their development. Mature hookworm larvæ, as well as those of *Trichostrongylus* and *Strongyloides,* usually invade the definitive host *via* the skin, and require an involved passage through the venous circulation to the lungs, thence out into the air passages and over the epiglottis into the digestive tract, passing on into the ileum where they complete their growth. If, however, mature hookworm larvæ are directly introduced into the intestine, they may pass through the stomach without injury and, on arrival in the ileum, attach themselves to the mucosa and grow to adulthood. *Œsophagostomum* larvæ, when swallowed, pass through the stomach and ileum into the colon, where they burrow into the mucosa, set up an inflammatory process, and become encapsulated, only to emerge later and become attached by their heads to the wall of the large intestine. The mature embryonated eggs of *Ascaris lumbricoides* hatch normally only after passing through the stomach into the small intestine, whence the free rhabditiform larvæ penetrate through the intestinal wall into the portal circulation or the lymphatics, and, on arrival in the pulmonary capillaries, break through into the air passages, and reach the intestine again *via* the epiglottis. Larvæ of *Spirocerca sanguinolenta*, a common parasite of the dog in the Orient, utilize the stomach wall through which to gain entry into the portal system, and upon reaching the lungs *via* the venous circulation, continue their passages through the pulmonary capillaries into the arterial circulation. In the case of *Trichinella spiralis,* the viviparous female, after copulation, bores into the intestinal glands and discharges her brood of larvæ, which apparently pass through the lymphatics into the right heart and lungs, thence into the arterial

circulation, finally coming to lodge in the muscles, where they encyst. Here they remain until the infected flesh is ingested by another host, whereupon the larvæ excyst and develop into adult worms.

The position of the primitive adult nematode parasite in its definitive host was most probably in the intestinal tract. Species in which the adult worms are now adapted to other organs or tissues, must have come upon their present site of residence through lodgment of the larvæ passing *en route* through such channels. Thus *Wuchereria bancrofti* in the lymphatics; *Dirofilaria immitis* in the right heart of the dog; *Onchocerca* in subcutaneous pockets and *Fuellebornius* (= *Dracunculus*) *medinensis* in subcutaneous tissues; *Spirocerca sanguinolenta* in the wall of the aorta of the dog; *Dioctophyme renale* in the kidney or abdominal cavity; and *Trichosomoides crassicauda* in the bladder of the rat,—all these species now live in foci which are evidently secondary to an original habitat in the intestine, a position that has long since been relinquished in favor of the secondary site. In *Spirocerca sanguinolenta*, moreover, even the secondary site has been abandoned as a habitat for the development of the mature worm and a return has been made to the wall of the intestine, to provide for an outlet of the eggs to the outside world. Finally, species in remote tissues, such as the lymphatics, having an outlet for larvæ to reach the blood, have provided most effectively for transfer of their larvæ to new hosts through the intermediary of biting insects.

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CHAPTER XXIII.

THE TRICHOSYRINGATE NEMATODES.

ORDER TRICHOSYRINGATA WARD, 1917.

(Trichinella, Trichocephalus and Related Forms.)

The trichosyringate nematodes, as designated by Ward (1916, 1917), include those species which are here grouped in the suborder **Trichinellata** (= **Trichurata** Skrjabin, 1916) and the suborder **Mermithata**. All of these forms are characterized by having a filariform body, at least in its anterior portion, and by having an esophagus consisting of a chitinous tubule running through the center of a single row of cells arranged end to end. The suborder **Trichinellata** contains three genera parasitic in man, *Trichocephalus, Hepaticola* and *Trichinella*, each of which is represented by a single species. The mermithate nematodes are occasionally accidental contaminators of the human body during their larval stage.

Suborder Trichinellata nom. nov., pro Trichurata Skrjabin, 1916, represented by the

Superfamily Trichinelloidea Hall, 1916.

The species of this group have a complete intestinal tract with an anal opening. The females have bluntly rounded posterior ends, while the males are curved ventrad and possess either a single spicule or none at all. The females have but a single ovary. Of the three recognized families in this group the **Trichinellidæ** contains one and the **Trichocephalidæ** contains two of the three species parasitic in man.

Family TRICHINELLIDÆ Ward, 1907.

This family has been created for a single species, *Trichinella spiralis,* in which the posterior end of both the males and females is only slightly thicker than the anterior end. The male lacks a copulatory spicule and sheath. The female is viviparous.

Genus Trichinella Railliet, 1895.
(genus from *θρίξ,* thread).

1. **Trichinella spiralis** (Owen, 1835) Railliet, 1895.

Synonyms.— *Trichina spiralis* Owen, 1835; *Trichina affinis* Diesing 1851 *pro parte*; *Trichina spiralis hominis* Kraemer, 1853; *Pseudalius trichina* Davaine, 1862.

Historical.—*Trichinella spiralis* was first observed in the larval stage, encysted in the muscular system of patients who came to autopsy in London (Peacock, 1828; Hilton, 1833). The larvæ were again found in London (Paget, 1835) at the autopsy of an Italian who had died of tuberculosis. They were referred to Owen, who described the worms and named them *Trichina spiralis*. Soon afterward other cases of human infection were reported from England, Germany, Denmark and North America. In 1846 Leidy (Philadelphia) first recorded the presence of the larvæ in the pig. The researches of Leuckart (1855) and Virchow (1859) showed that *Trichinella* larvæ, when fed to an appropriate experimental animal, became adult in a few days, and that the females were viviparous. Zenker (1860) first demonstrated that *Trichinella* infection in man was a serious disease. This led to renewed efforts on the part of German investigators, who soon elucidated the complete cycle of development of this worm and demonstrated that the source of human infection was infested pig flesh consumed raw or insufficiently cooked. The disease, which was proved to be both endemic and epidemic in its nature, and to be capable of producing a high mortality, became an important public health problem and led not only to careful epidemiological surveys but to inspection of meats and to other precautions to reduce the source of human infection.

Structure of the Adult Worms and the Life History.—The male worm (Fig. 180*A*) has a length measurement of 1.4 to 1.6 mm. and a greatest transverse diameter of 40 to 50 μ. It is more attenuate anteriorly and more fleshy posteriorly. The cloaca opens at the posterior end of the worm; it is evertible during coitus; it is guarded by two conspicuous conical papillæ. The female (Fig. 180*B*) measures 3 to 4 mm. in length and has a greatest transverse diameter about one and a half times that of the male. The adult worms are attached to or buried in the intestinal mucosa of the host. Here the males impregnate the females shortly after maturing and thereafter soon die. The females then increase to their maximum size, and bore more deeply into the mucous membrane or into the villi, or may even work their way through the intestinal wall to the peritoneum or mesenteric lymph glands. By this means the viviparous young are deposited in the lymphatics, and probably also in the mesenteric veins. According to Leuckart as many as 1500 larvæ are thus deposited by each female. These larvæ (Fig. 180*C*) measure 90 to 100 μ in length by 6 μ in diameter and are capable of passing both the hepatic and pulmonary filters during the period of migration. Between the seventh and the twenty-third day after infection they are found in the arterial circulation. They migrate from the left heart to all parts of the body but they are capable of developing further only in striated muscle. The first larvæ reach their destination about the ninth day after infection. There follows a continu-

ous stream of migrating larvæ for five or six weeks, or as long as the female worms are alive in the intestine. During the period of migration the larvæ can be detected in peripheral blood. On arriving in

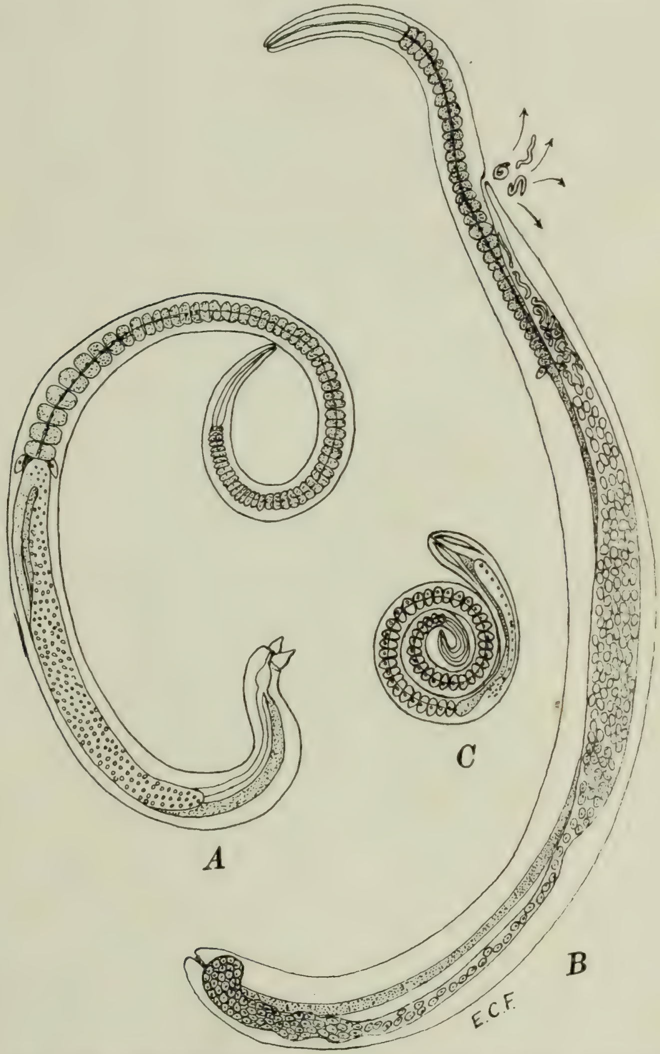

FIG. 180.—*Trichinella spiralis; A*, adult male worm; *B*, adult female worm; *C*, larva; *A* and *B*, × 90. (After Yorke and Maplestone, Nematode Parasites of Vertebrates); *C*, × 660. (Adapted from Staubli.)

striped muscle they soon become encysted. The cyst capsule is an adventitious ellipsoidal object with blunt ends (Fig. 181); it is considerably larger than the larvæ which is tightly coiled up inside.

While encystment may take place in any striped muscles in the body of the host the larvæ appear to have a particular predilection for the diaphragm, the muscles of the larynx, tongue, abdomen and intercostal spaces (*e. g.*, those muscles which are characterized by constant activity). They are particularly numerous near the points of tendinous attachment. Upon encystment the larvæ may remain viable for many years. Such larvæ have been found in the pig eleven years and in man twenty-five to thirty-one years after infection. Larvæ which have reached their position in the striped muscles but have not yet become encysted are also capable of devel-

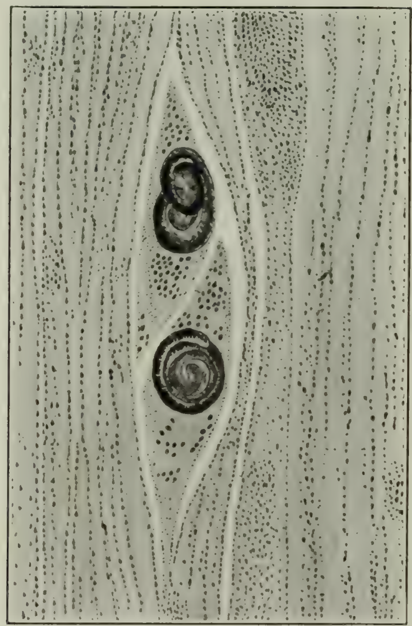

Fig. 181.—Encysted trichinella larvæ in striped muscle. (Original.)

oping to maturity upon reaching the gut of suitable mammals. Frequently the encysted larvæ undergo a process of calcification from six to nine months after encystment. Usually the capsules alone become impregnated with lime, beginning at the poles where calcification is heaviest and extending toward the middle, finally providing complete sarcophagi for the young worms and thus effectively protecting the host tissue from their toxic by-products. Calcification may also involve the larvæ themselves or the larvæ may become calcified without involvement of the cyst.

Viable *Trichinella* larvæ in infested flesh, upon being ingested by the human or other appropriate host, become excysted in the

medium of the gastric juice and pass through to the duodenum, where some of them become attached to the wall and soon grow to adulthood. If adult females are not favorably situated for the deposition of their larvæ into lymph or venous channels the larvæ may escape into the intestinal lumen and be passed in the feces.

Thus two hosts are required for the complete life cycle of *Trichinella spiralis*, each host harboring both the definitive and the larval stages of the worm. The black rat and the brown rat are the present-day reservoir hosts of the infection. Their cannibalistic nature serves to propagate the infection, while animals such as pigs, wild boars, dogs, cats, foxes, bears and martens, which feed on rats, contract the infection from the rodent reservoirs. Finally man becomes infected from consuming unsterilized pig flesh. Rodents, pigs and human beings are all easily infectible, while cats and dogs are seldom infected. The infection has been reported from reservoir hosts from practically all countries throughout the world. However, neither pigs nor rodents have thus far been found infected in China, thus refuting the theory that the disease was introduced into Europe with the Chinese pig (1820–1830). Human infection corresponds to regions in endemic areas where man is fond of raw pig flesh. Thus trichinized reservoir hosts were apparently as common in North America as in Germany during the middle and latter part of the nineteenth century but human infection was appreciably less.

Pathogenicity and Symptomatology.—The disease trichinelliasis or, more familiarly, trichinosis, may be divided into three stages: (1) the period of invasion of the host, (2) the period of migration of the larvæ, and (3) the period of encystment and tissue repair. During the first period the symptoms are primarily gastro-intestinal, consisting of nausea, vomiting, diarrhea or dysentery and colic. These symptoms are due to intense catarrhal inflammation of the intestinal tract and at times profuse hemorrhage produced by the adult worms. This occurs through the seventh day, when migration of the larvæ usually begins, but rheumatic muscular pains, symptomatic of migration, may begin slightly earlier. The second period is one of more or less profound myositis, involving the diaphragm, muscles of the arm and leg, intercostals, larynx and mouth, and causing intense pain, together with difficulty in respiraton, mastication and speech. Edema may be an accompaniment and dyspnea may be intense. Hypereosinophilia rapidly develops and leukocytosis may be pronounced. There is frequently an elevation of temperature to 40° C. and occasionally even to 41° C. The fever is usually remittent. These symptoms occur roughly about the second week. The third period is the critical one. There is frequently edema, particularly of the face. Marked cachexia develops, due to absorption of toxins from the larvæ. In grave cases delirium, pulmonary discompensation and coma supervene and the patient

usually succumbs. In light cases gradual subsidence of the symptoms is indicative of slow recovery. The continuous deposition of *Trichinella* larvæ into the lymphatics during this period will result in complications. Histologically the muscle fibers immediately surrounding the invading and encysting larvæ degenerate, the transformation consisting in the loss of the transverse striæ and an increase in the number of nuclei. The growth of the larvæ results in the swelling of the adjacent muscle fibers, thickening and modification in structure of the sarcolemma, and proliferation of the intermuscular tissue. The larvæ attain a length of 0.8 to 1 mm., their growth being at the expense of the surrounding muscle fibers which gradually become absorbed, while the hyperplastic connective tissue produces the capsule. These capsules invariably lie with their long axes in the direction of the muscle fibers. Calcification is the final outcome of the invasion of fat cells at the poles of the cysts.

Diagnosis.—The disease requires to be differentiated in its early stages from ptomaine poisoning, cholera and dysentery. Later typhoid must be ruled out. Nephritis may be excluded by the absence of albumin in the urine. A marked eosinophilia (15 to 50 per cent) together with the other characteristic symptoms is highly suggestive of trichinelliasis, while the recovery of the adult males in the feces during the initial diarrhea or of the larvæ in the blood during the period of migration is specifically diagnostic. In addition, the removal by biopsy of a small piece of the deltoid, biceps or gastrocnemius muscle from the vicinity of its tendinous attachment and examination in a trichina press under low power of the microscope may reveal the presence of precystic or encysted larvæ

Therapeusis.—There is no known treatment for terminating the disease before it runs its course. After specific diagnosis has been made palliative measures should be used and the patient made as comfortable as possible.

Prognosis.—In heavy infections, grave; in less intense infections, fairly good. In epidemics from 0.5 to 30 per cent of the stricken patients succumb. If the patient can withstand the active periods of the disease, it gradually subsides and slow recovery is effected. The numerous microscopic cysts in the striated muscles appear to produce no appreciable lasting inconvenience to the host.

Prophylaxis.—With a knowledge that the pig is the reservoir hosts of the infection, careful inspection of meats in the large slaughter houses in Europe and America has reduced the epidemics of serious cases to a minimum, but there are undoubtedly hundreds of undiagnosed cases throughout the less populous endemic areas. Ordinary methods of curing meat by smoking or salting are ineffectual. Drying is a contributary cause to destruction of the larvæ. Ransom and his colleagues have shown that refrigeration at 5° F. for not less

than twenty days renders infested flesh practically innocuous. Boiling of trichinized meat for a period of one-half hour for every pound of flesh is the only absolutely safe method thus far known. Physicians should be admonished to use special precautions not to infect themselves in examining *postmortem* cases in which there is a possible history of *Trichinella* infection.

Family TRICHOCEPHALIDÆ Baird, 1853.

The members of this family have a characteristic capillary anterior end. The male worms have a copulatory sheath and usually possess a copulatory spicule. The eggs are barrel-shaped and possess clear mucoid polar plugs. The life cycle of these species is direct, the worms requiring but one host. They live in the intestinal tract, liver or urinary bladder of mammals and birds.

Genus Trichocephalus Schrank, 1788.
(genus from θρίξ, hair and κεφαλή, head).

2. **Trichocephalus trichiurus** (Linnæus, 1771) Blanchard, 1895.

Synonyms.—*Ascaris trichiura* Linn., 1771; *Trichocephalus hominis* Schrank, 1788; *Trichuris hominis* (Schrank, 1788) Bruguière, 1791; *Trichocephalus dispar* Rud., 1802; *Mastigodes hominis* (Schrank, 1788) Zeder, 1803; *Trichuris trichiura* (Linn., 1771) Stiles, 1901.

Structure of the Adult Worms and the Life History.—The adult worm, *Trichocephalus trichiurus*, commonly lives in the human cecum, but at times it is found in the appendix vermiformis and the colon, and on rare occasions in the posterior part of the ileum. Man is the only known host of this species of the genus, unless the form found in the pig is proved to be the same species. The male worm measures 30 to 45 mm. in length, the anterior three-fifths being a capillary tubule and the posterior two-fifths being more fleshy. The caudal extremity is coiled ventrad as much as 360 degrees or even more (Fig. 182*A*). The single, lanceolate spicule, which measures 2.5 mm. in length, protrudes through the retractile sheath at the posterior extremity of the body. The sheath has a bulbous end and is beset with numerous recurved spines, which serve to hold the male in position at the time of copulation. The female worm (Fig. 182*B*) measures from 35 to 50 mm. in length, is bluntly rounded at the posterior end, and has approximately the same proportions of capillary and fleshy parts as the male. The vulvar opening is at the anterior extremity of the fleshy portion. The worm is oviparous, the eggs when extruded containing a single blastomere. These eggs are barrel-shaped, possess an outer and an inner shell and have transparent mucoid plugs at the poles. They measure 50 to 54 μ in length by 22 to 23 μ in breadth. The first division of the egg is transverse but unequal. The second is also

transverse, being a division of only the blastomere at the vegetal pole. The third division is a longitudinal division of the medial cell. Thus the four-cell stage is the result of three rather than two segmentation stages. Development of the rhabditiform larva within the egg takes place outside the body of the host. The time required for this development depends on the type of environment.

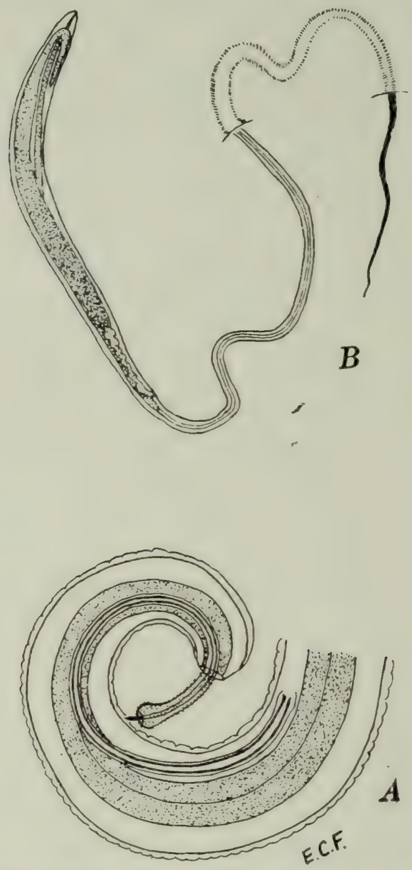

FIG. 182.—*Trichocephalus trichiurus; A*, posterior end of male worm, showing copulatory spicule; *B*, entire female worm; *A*, × 35; *B*, × 6. (Adapted from Yorke and Maplestone, Nematode Parasites of Vertebrates.)

Extremely dry conditions or those in which oxygen is practically lacking delay the process for months or even for years. Even under favorable conditions two or more weeks are required. Human beings upon swallowing the fully embryonated egg as a contamination of food or drink become infected. The various steps in the life cycle as first demonstrated by Grassi and Calandruccio and more recently

confirmed by Fülleborn, are as follows. The egg-shell is digested in the intestinal juices, the larva passes through to the cecum or adjacent region of the bowel, and without further complications attaches itself to the intestinal wall and grows into an adult worm.

Pathogenicity and Symptomatology.—Much has been written about the pathogenicity of the human whipworm but very few facts are known. In tropical and oriental countries the infection is common, from one to ten worms being present in the cecum in 25 or more per cent of the population. No appreciable clinical symptoms are usually elicited from persons harboring such infections. The worms are attached by their anterior ends to the mucosa, a film of mucus surrounding the attachment end. In such cases, there is ordinarily no tissue reaction and the adjustment of host tissue to parasite may be said to be that of complete equilibrium. Occasionally the attachment end of the worm extends through to the submucosa or the muscularis and on rare occasions it may possibly perforate through to the body cavity. Under such circumstances a more or less serious inflammatory reaction may result. If the worm comes to lodge in the lumen of the appendix it may cause occlusion of this organ. In some individuals, particularly children, toxic symptoms, consisting of a low-grade anemia, insomnia, and sympathetic reflexes, and rarely an urticaria are produced, but the eosinophilia in such cases is never profound as in trichinella infection. Perhaps the most serious rôle played by *Trichocephalus trichiurus* is the opportunity which the worm offers for secondary invaders such as typhoid, cholera, dysentery and tetanus bacilli to secure a lodgment in the tissues of the host, but the evidence in such concomitant infections is at best only circumstantial and not necessarily convincing. Cases of appendicitis have probably been occasioned by the presence of one or more whipworms in the lumen of the appendix.

Diagnosis.—Upon recovering the characteristic eggs from the feces of the patient.

Therapeusis.—No specific treatment has yet been successfully used in human cases. Oil of chenopodium at times dislodges all or part of the worms. Hall (1926) found mercurochrome given to dogs in capsules effective in dislodging 88 per cent of the dog whipworms.

Prophylaxis.—*Trichocephalus trichiurus* is practically cosmopolitan in its distribution, but is much more common in warm moist regions than in colder climates. Nevertheless the eggs of this species can survive long-continued drought and a considerable amount of putrefaction in diluted night-soil. Human infection results from ingestion of embryonated eggs derived from night-soil or earth that has been fertilized with human manure. There is also the possibility that the whipworm of the pig (*T. suis*), which is morpho-

logically indistinguishable from the human species, may be infective for man. To avoid *Trichocephalus* infection care should be taken to cleanse the hands before eating and suspected raw fruits and vegetables should be plunged into boiling water for a few seconds before consumption.

Related Species.—Many closely related species of *Trichocephalus* are found in other mammals, including *T. campanulus* and *T. serratus* in the cat, *T. discolor* in the cow, *T. leporis* in the rabbit, *T. muris* in rats and mice, *T. ovis* in sheep and goats, *T. suis* in the pig, and *T. vulpis* in the dog and fox.

Genus Hepaticola Hall, 1916.

(genus from *hepar,* liver and *incola,* inhabitant).

3. **Hepaticola hepatica** (Bancroft, 1893) Hall, 1916.

Synonym.—*Trichocephalus hepaticus* Bancroft, 1893.

Hepaticola hepatica is a trichocephalid nematode living in the liver tissues of the Alexandrine rat, the black rat, the brown rat, the domestic mouse, the North American prairie dog, and the European hare. One case has been recorded from man, a British soldier in India. The worm also develops normally in the dog. Natural infections in reservoir hosts have been recorded from America, Europe, Australia and India; rats and mice are also not infrequently infected in China and Japan. When dissected out of the host tissues the body of this worm bears a general resemblance to *Trichocephalus,* although it is much more delicate and its anterior capillary portion is proportionally shorter than that of *Trichocephalus* (Fig. 183*A*). In the male the spicule is lacking. The vulvar opening in the female is in the esophageal region. The worms are oviparous. The eggs (Fig. 183*B*) are of the characteristic pattern for the family, but are distinguished by having the outer shell perforated with minute channeled pores. The eggs of the related species, *H. soricicola* Nishigori, 1924, are longer and more slender.

The life cycle of this species, like that of *Trichocephalus,* is direct, requiring only a single host. According to Nishigori the eggs are deposited in the parenchyma of the liver and are not excreted. Less than a month after they are laid they contain mature embryonated larvæ. These are transferred to the next host when the infected organ is eaten by that host. They hatch in the intestine (Fig. 184) and the free larvæ penetrate the wall, whence the majority migrate to the liver *via* the portal veins. A few aberrant individuals may pass the portal filter and continue through to the lungs, brain, kidney or skin. From twenty-seven to twenty-eight days are required for the maturity of the larvæ into adult worms and the deposition of a new generation of eggs.

Pathogenicity and Symptomatology.—The pathological process consists in the formation of fibrous connective tissue around depots

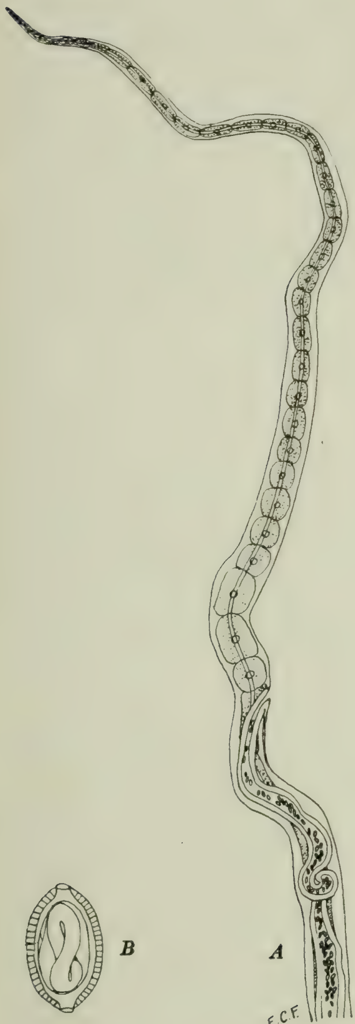

FIG. 183.—*Hepaticola hepatica; A*, anterior end of female worm, showing capillary esophagus and vulva, × 16; *B*, embryonated egg, × 295. (After Nishigori.)

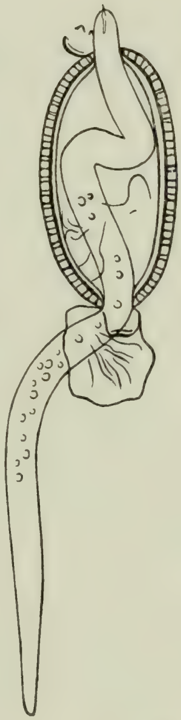

FIG. 184.—Larva of *Hepaticola hepatica* emerging from egg-shell. Highly magnified. (After Fuelleborn, Archiv. für Schiffs- und Tropen-Hygiene.)

of eggs and in light infections involves only a localized area. In heavy infections, however, the liver of the rodent host may be affected by a generalized cirrhosis. Toxic symptoms, consisting of

a diarrhea, dyspnea and congestion of the liver, may result from heavy infections. In the single human infection on record, reported by MacArthur from material furnished by Dive, the symptoms were said to resemble pyemia, and *postmortem* examination revealed a suppurative condition of the liver with spongy areas, which, under the microscope, revealed the presence of large masses of *Hepaticola hepatica* eggs.

Diagnosis.—Possible only at *postmortem*, by examining scrapings of the infected organs or by sectioning the tissue and finding the characteristic eggs.

Therapeusis.—Unknown.

Prophylaxis.—Infection among rodents is doubtless due to cannibalism. Due to the source of infection human cases are bound to be rare.

Suborder Mermithata, nom. nov.,

represented by the

Superfamily Mermithoidea Wuelker, 1924.

This group consists of several genera all grouped under the family **Mermithidæ** Braun, 1883. The adult worms are readily visible to the naked eye and some reach the length of 10 to 20 cm. They are opaque objects, with a pointed anterior end, a tapering body and smooth, finely striated cuticle. Behind the esophagus the intestine is reduced to a mere cord of cells without a cavity and in some species is completely lacking for a part of the way. In females the anal opening is represented by a slight indentation of the cuticle; in males the cloaca persists to permit an outlet for the spermatozoa, but the intestine anterior to the cloaca is atrophied. The worms are parasitic in the body cavity of insects, particularly grasshoppers, during their larval life and are free-living as adults. The commonly accepted name for the larval stage is *Agamomermis*. Two cases of human infection with larval mermithids are recorded by Stiles and Hassall (1926), both of which were originally described by Leidy. The former, *Agamomermis hominis oris* (Leidy, 1850), was about 14 cm. in length and was obtained from the mouth of a child. The second, *Agamomermis restiformis* (Leidy, 1880), was 65 cm. long and 1.5 mm. in diameter and was recovered while attempting to emerge from the penial opening of an adult white man. A third case of infection with a mermithid worm has been reported by Baylis (1927). The worm is said to have been passed by a woman thought to be suffering from uterine cancer. The specimen (alcoholic preservation) was of a pinkish flesh color, totaling about 56 cm. in length and having a maximum breadth of a little less than 1 mm.

The presence of mermithids in the human body is undoubtedly accidental, due to ingestion of the worms in food, water or moist

earth into which the worms have found their way after migration from the invertebrate host, or due to swallowing the invertebrate host with its parasitic progeny.

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CHAPTER XXIV.

THE MYOSYRINGATE NEMATODES.

ORDER MYOSYRINGATA WARD, 1917.

THIS order contains great assemblages of free-living and parasitic species. Among them are some of the most important helminth parasites of man. They are all characterized by having a prominent muscular esophagus with a triradiate lumen. The human myosyringate nematode parasites are grouped in five suborders, each having one or more superfamilies, which, in turn, are represented by one or more families. These families with their respective species will be taken up *ad seriatim* according to the classification presented in Chapter XXI (pp. 307–313).

Suborder Rhabdiasata Cram, 1927.

(STRONGYLOIDES AND RELATED FORMS.)

From a structural viewpoint the members of this group are relatively simple forms. Biologically many of them are on the borderline between a free-living and a parasitic condition. For some the mode of existence is facultative; for others environmental factors appear to be the determining element as to whether the worm at any particular time is free-living or parasitic. The species recorded from man are grouped under the families **Rhabdiasidæ** and **Tylenchidæ**.

Family RHABDIASIDÆ Railliet, 1915.

This family contains species which previous authors have usually placed under the **Anguillulidæ** or **Angiostomidæ**, both of which groups were inadequately described. More recent studies have served to demonstrate the fundamental characters of the present family grouping, consisting of a short prismatic or tubular buccal cavity, and an esophagus with a posterior valvate bulbar swelling, and frequently an anterior bulbar swelling. The species which have been recorded from man belong to the genera *Strongyloides*, *Rhabditis* and *Anguillula*.

GENUS STRONGYLOIDES GRASSI, 1879.
(genus from στρογγύλος, round and εἶδος, similar).

1. **Strongyloides stercoralis** (Bavay, 1876) Stiles and Hassall, 1902.

Synonyms.—*Anguillula stercoralis et A. intestinalis* Bavay, 1877; *Strongyloides intestinalis* (Bavay, 1877) Grassi, 1879; *Leptodera intestinalis* Cobbold, 1879; *Pseudorhabditis intestinalis* Perroncito, 1881; *Rhabdonema strongyloides* Leuckart, 1883; *Rhabdonema intestinale* Blanchard, 1886.

Historical.—In 1876 Normand discovered in the feces of French soldiers, who had returned from Cochin China suffering from diarrhea, a large number of minute nematodes which Bavay described the next year as *Anguillula stercoralis*. Five of the patients died as a consequence of the diarrhea and at *postmortem* Normand recovered numerous other nematodes from their ileum, biliary and pancreatic ducts. These latter Bavay designated as *Anguillula intestinalis*, believing them to be different from the previously described forms, and supposing that both species were involved in the "Cochin-China diarrhea." Soon afterward Grassi (1879) found both the intestinal and the stercoral types and Perroncito (1880) the stercoral type. In 1882 Leuckart demonstrated that the two forms belonged to one and the same species, which was heterogenetic. Askanazy (1900) found that the parasitic generation (females) lives in the wall rather than the lumen of the intestine. Durme (1902), Ransom (1907) and Fülleborn (1914) have shown that members of the genus *Strongyloides* utilize the same route of invasion and of migration through the host which Looss first demonstrated for the hookworm.

The Parasitic Females.—No male worm has ever been found in the parasitic generation of *Strongyloides stercoralis*. The view first proposed by Leuckart (1882), that the parasitic phase of the life cycle consisted of a protandrous hermaphrodite was later abandoned for Rovelli's theory (1888) that the female of the parasitic generation was a parthenita. Recent studies by Sandground (1926) incline to the belief that the parasitic females are syngonic, although actual proof remains incomplete. The parasitic female (Fig. 185 *A*) is a colorless, nearly transparent filiform object, measuring about 2.2 mm. in length and varying from 30 to 75 μ in transverse diameter. The integument has very delicate striations. The nearly cylindrical esophagus extends through the anterior third of the body. The posterior end of the body is pointed. The anal opening is ventral in position, a short distance in front of the caudal extremity. The vulva opens ventrad at the junction of the middle and posterior thirds of the body. The ovaries, oviducts and uteri number two each, one set being disposed anteriad and one posteriad. These females bore deeply into the mucous membrane of the intestine and not infrequently into the epithelium of Lieberkühn's glands, where they secure nourishment and later oviposit. Here the eggs, which are thin-shelled transparent oval objects measuring 50 to 58 μ in length by 30 to 34 μ in transverse diameter, complete their

development and hatch, whereupon the embryos escape into the intestinal lumen and are passed in the feces as rhabditiform larvæ. Only in case of severe diarrhea or of a strong purge are the eggs of this species recovered from the feces. The larvæ when first hatched measure 200 to 250 μ in length by 16 μ in breadth but may grow to two or three times this size by the time they are evacuated in the

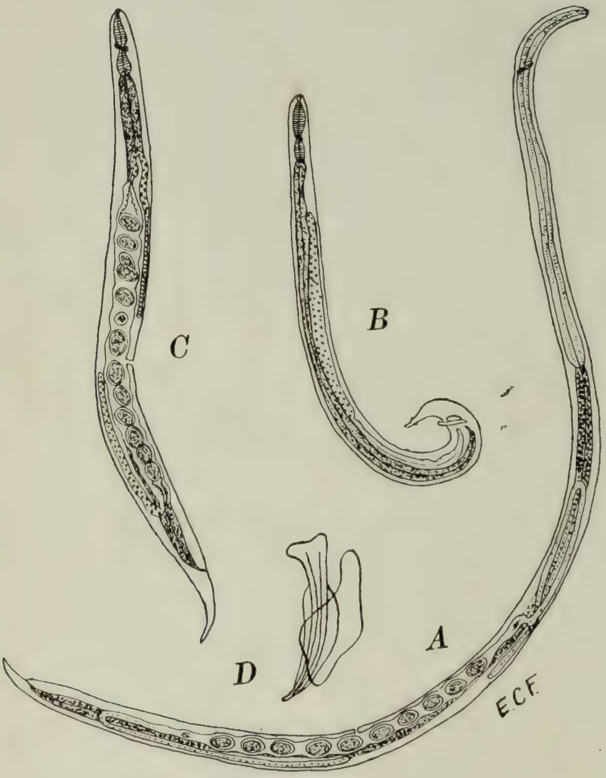

Fig. 185

Fig. 186

Fig. 185.—*Strongyloides stercoralis.* *A*, mature female of the parasitic generation. × 90. *B*, mature free-living male. × 90. *C*, mature free-living female. × 90. *D*, spicule and gubernaculum of male, greatly enlarged. (*A*, *B*, *C*, after Yorke and Maplestone, Nematode Parasites of Vertebrates; *D*, schematic adaptation from Looss.)

Fig. 186.—Rhabditiform larva of *Strongyloides stercoralis.* × 310. (After Looss.)

feces. These larvæ (Fig. 186) are typically rhabditiform, with an elongate esophageal bulbus and a pyriform posterior bulbus. The intestine extends through the posterior two-thirds of the body and the genital primordia are situated on the ventral aspect just in front of the posterior third. These larvæ are extremely active and cannot always be detected in ordinary smear preparations. They

differ from the homologous stage of hookworm larvæ in being less attenuate posteriorly and in having a much shorter buccal vestibule. The development of these larvæ, once they have escaped from the human body, may be either direct or indirect, depending on a mechanism which has not yet been determined. Carefully controlled experiments have shown that neither physical nor chemical factors of the environment are primarily involved. Likewise it has been experimentally demonstrated that Leichtenstern's theory, of a tropical strain which utilizes the indirect or heterogenetic mode of development and a temperate strain which develops directly, is untenable. The use of the Baermann apparatus (see page 532) for isolating larvæ and adults of this and related species from fecal cultures has furnished Sandground (1926) with considerable evidence favoring the view that cultures ordinarily yield both the direct and indirect types. Only in the case of *Strongyloides fülleborni*, a parasite of catarrhine primates, is the direct cycle apparently lacking.

Heterogenetic Development.—In case of heterogenetic development the rhabditiform larvæ moult and within thirty hours are completely developed into sexually mature males and females (the free-living unisexual adults). These worms (Fig. 185, *B*, *C*) are essentially different in size, shape and internal organization from the parasitic female. The male measures about 0.7 mm. in length by 40 to 50 μ in diameter and the female 1 mm. in length by 50 to 75 μ in diameter. Both sexes have an esophagus similar to that of the rhabditiform larva. The male is devoid of caudal alæ but has an unpaired spicule with an accessory gubernaculum (Fig. 185 *D*). In the female the uteri are divergent as in the parasitic generation. The thin-shelled transparent eggs measure 70 by 40 μ. In old females of the free-living generation the eggs may hatch in the uterus. The rhabditiform larva which escapes from the egg-shell is distinguishable from that developed by the parasitic female. After three or four days these rhabditiform larvæ moult and become metamorphosed into elongate filariform larvæ, which are the infective stage for the host. In the case of direct development the rhabditiform larvæ evacuated in the feces moult and become transformed directly into filariform larvæ, without the intercalation of the free-living generation. Both the filariform larvæ, developed directly as the progeny of the parasitic generation, and those which are the progeny of the free-living generation usually enter the mammalian body *via* the skin or the oral mucosa, penetrate through the tissues into the venous circulation, thence through the right heart into the lungs, breaking out from the pulmonary capillaries into the alveoli and, upon reaching the respiratory tract, migrate up to the epiglottis, thence into the intestinal tract and on arrival in the ileum burrow into the tissues and grow into adult worms. Mature filariform larvæ of the genus *Strongyloides*, like those of *Ancylostoma*,

may be swallowed and on arrival in the ileum, grow directly into mature individuals. Seventeen days is required from the time of invasion until the worms are mature and rhabditiform larvæ appear in the feces. An unconfirmed report of the presence of *S. stercoralis* in the urino-genital tract is on record (Robitschek).

The Hosts of S. Stercoralis and Related Species.—Man is the optimum host of *Strongyloides stercoralis*. A worm indistinguishable from this species has been recorded from dogs in China, Japan and India, while the human strain can be successfully implanted in this host for several months but eventually dies out. Cats and apes have been infected with the worm but it appears to be a very transient parasite in these latter hosts. Closely related species occur in the following natural hosts: *Cebus hypoleucus* (*Strongyloides cebus* Darling, 1911), *Anthropopithecus troglodytes* and *Cynocephalus babuin* (*S. fülleborni* v. Linstow, 1905), *Bos taurus* (*S. longus bovis* de Gaspari, 1912), *Bos taurus* (*S. vituli* Brumpt, 1921), *Nasua narica panamensis* (*S. nasua* Darling, 1911), *Antilocapra americanus* (*S. ovocinctus* Ransom, 1911), sheep, goats, rabbits, rats, pigs, etc. (*S. papillosus* [Wedl, 1856] Ransom, 1911), horses (*S. westeri*, Ihle, 1917), dogs (*S. canis* Brumpt, 1921), macaques (*S. simiæ* Hung and Hoeppli, 1923) *Hydrochœrus hydrochœra* (*S. chapini*, Sandground, 1925) and *Mus norvegicus* (*S. ratti* Sandground, 1925). Apparently none of these species is capable of becoming permanently established in the human intestinal tract.

Geographical Distribution of S. stercoralis.—The geographical distribution of *S. stercoralis* infection parallels that of human hookworm disease. It is much more common in the moist tropics and is uncommon in the cold temperate zones except where local conditions also favor the development of the hookworm. However, in practically every locality the incidence of strongyloidiasis is less than that of hookworm infection.

Pathogenicity and Symptomatology.—From the time of the discovery of the worms in individuals suffering from diarrhea, which had probably been contracted in Cochin, China, the adult *Strongyloides stercoralis* has been commonly believed to be the causative organism of a severe diarrhea. It is known that the infective filariform larvæ, on entering the skin, produce a dermatitis of the same type as that arising from the invasion of hookworm larvæ. No clinical symptoms appear to be recorded for the period during which the larvæ are *en transit* through the lungs. Upon invasion of the intestinal mucosa they provoke a catarrhal inflammation more or less severe, while the mature worms in ovipositing and the young larvæ in escaping from the mucosa interfere with the normal functioning of the glands and frequently give rise to a diarrhea, which is at times characterized by flecks of bloody mucous or at least by the presence of occult blood. Occasionally urticarial rash and

edema may accompany the infection. Care must be exercised to exclude other organisms as the cause of the diarrhea or other symptoms.

Diagnosis.—This is based on the recovery of the typical rhabditiform larvæ (Fig. 186) from the feces or, after the administration of a strong purgative, of the unhatched embryonated eggs. These need not be confused with hookworm eggs, since in the human bowel the latter develop *in ovo* to the rhabditiform stage only in case of pronounced constipation and rarely hatch in the unevacuated feces. In light infections the use of the Baermann apparatus (p. 532) is useful in recovering the larvæ from the feces. If the feces is allowed to stand for thirty hours or more the free-living generation may have developed.

Therapeusis.—No efficient treatment has been devised. Anthelminthics such as oil of chenopodium, *filix-mas* and carbon tetrachloride are recommended by some clinicians, while others find flower of sulphur helpful.

Prophylaxis.—The skin should be protected from infective earth or fecal contamination. Specific sanitary measures respecting the disposal of human night-soil are similar to those for hookworm prevention.

GENUS RHABDITIS DUJARDIN, 1845.
(genus from *ραβδίον*, a small rod.)

2. **Rhabditis pellio** (Schneider, 1866) Buetschli, 1873.

Synonyms.—*Pelodera pellio* Schneider, 1866; *Anguillula mucronata* Grube, 1849; *Angiostoma limacis* Dujardin, 1845 of Lieberkühn, 1858; *Rhabditis genitalis* Scheiber, 1880; *Leptodera pellio* (Schneider, 1866) Ward, 1903.

This worm is a facultative saprozoite of mammalian tissues. In its larval stage (*Anguillula mucronata*) it has been found to be resident in several species of earthworms; as an adult it lives normally in decomposing organic matter in the soil (Roffredi). The adult worms have a smooth cuticle. Their oral ends (Fig. 187 *A*) are provided with three broadly rounded lips, each having two pairs of small glistening papillæ. The oral cavity is externally cylindrical; internally it has an annular thickening. The esophagus is slightly swollen anteriorly and enlarges posteriorly into a bulbus provided with teeth. The male measures 0.8 to 1.05 mm. in length. The caudal extremity is provided with cordate alar appendages, supported by nine pairs of ribs (Fig. 187 *B*). The spicules are short and equal. The female measures 0.9 to 1.3 mm. in length. The caudal extremity is drawn out into a long conical projection. The vulvar opening is provided with two papillæ. The paired uteri are divergent and are tightly coiled. They contain hundreds of ripe eggs which develop *in situ*, hatch and invade the body cavity of

the mother worm, finally consuming all of the organs of the mother so that the larvæ finally appear to lie in a spindle-shaped sac consisting of the intact cuticle of the parent worm.

Scheiber (1880) found these worms in the urine of a female patient suffering from pyelonephritis, pneumonia and acute intestinal catarrh. The urine was acid and contained albumin, pus and blood. The adult worms were situated in the vagina and the larvæ were evacuated with the urine. The worms reported by Boginsky (1887) and by Peiper and Westphal (1888) from patients with similar histories probably belong to this species. Aubertot (1923) has

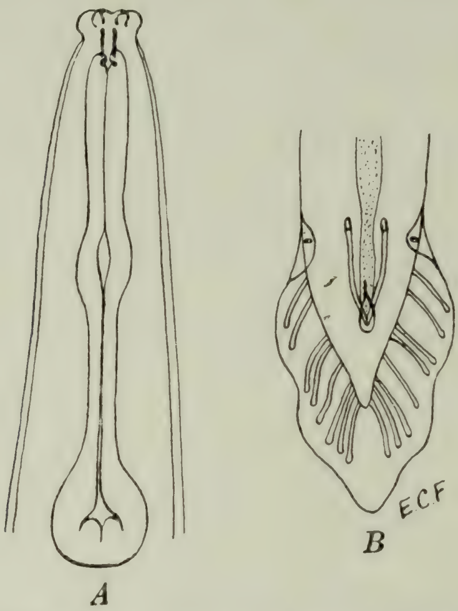

FIG. 187.—*Rhabditis pellio; A*, anterior end of worm, showing buccal cavity and esophagus; *B*, posterior end of male, showing spicules, bursa and bursal rays. × ca. 350. (After Oerley.)

shown that *R. pellio* may pass uninjured through the alimentary tract of the fly *Drosophilia*. Oerley (1886) has found that the worm will live in the vagina of a mouse. The fact that the Hungarian peasants use soil to make poultices would afford an opportunity for the worms to reach the vaginæ of women using such an application.

3. **Rhabditis niellyi** (Blanchard, 1885).

Synonyms.—*Anguillula leptodera* Nielly, 1882; *Leptodera niellyi* (Blanchard, 1885) Bl., 1890.

The description of this worm is based on the rhabditiform larval stage, found by Nielly and Bavay in a youth, aged fourteen years,

who had not been away from the vicinity of Brest and who had been suffering for six weeks from itching papules of the skin resembling "craw-craw" of West Africa. In each papule there were found one or more larvæ. These larvæ measured 0.33 mm. in length by 13 μ in diameter, were attenuate anteriorly and posteriorly, and had fine transverse striations on the cuticle. The mouth opened into a short pharynx, which was succeeded by an esophagus having two bulbs, of which the posterior was provided with teeth. The anal opening was situated a short distance from the posterior end.

The origin of these larvæ and the method by which they gained entrance to the skin is obscure. It seems most probable, however, that they are facultatively saprozoic or parasitic, that they gained entrance through the skin, and like *Gnathostoma* in creeping disease in man, were unable to reach a location where they could proceed with their development.

4. **Rhabditis hominis** Kobayashi, 1914.

Synonym.—*Rhabditis fœcalis* Watanabe, 1922.

This species of rhabditoid worm was described and named by Kobayashi (1914) from fresh fecal specimens of Japanese school children. It has more recently been reported from the Southern United States by Sandground (1925) who has studied it in considerable detail. Possibly the worm obtained by Frese (1907) by lavage of the human stomach is also the same species.

The adult worm (Fig. 188 *A*) is cylindrical in shape with anterior and posterior attenuations, and possesses a fine transverse striation to the cuticula. The buccal opening is provided with four labia; the cavity is cylindrical and measures 20 to 40 μ in length. The esophagus has a length of 0.17 to 0.2 mm. and consists of four parts (Fig. 188 *B*), an elongate muscular tube, followed by an anterior bulbus, a short median tubular portion, and finally a posterior cardiac bulbus. The intestine originates at the posterior end of the esophagus and continues to the subcaudal region of the body where it narrows and joins the short rectum. The latter opens through the anal pore in the female and into the cloaca in the male. The male measures 0.9 to 1.2 mm. in length by 30 to 50 μ in diameter. The caudal alæ are rather narrow bands surrounding the cloacal opening (Fig. 188 *C*). Each half is supported by six short ribs (*bp*). The two spicules (*s*) are equal; each has a knob-like head and a sharp point. A small gubernaculum (*g*) is situated mesad just within the cloaca. Mid-ventral in position some little distance anterior to the cloacal opening are an inconspicuous anterior and posterior papilla. The female measures 1.5 to 2.0 mm. in length by 0.12 mm. in diameter. The posterior end of the body is drawn out into a sharp point. The vulva is located in the middle of the body. The uteri are divergent. In young specimens each uterus is filled with 10 to 50 eggs,

which are ellipsoidal in shape and measure 44 by 28 μ, but the older worms are filled with rhabditiform larvæ which have already hatched. The youngest larvæ which escape from the mother worm (Fig. 188*D*) measure 240 to 300 μ in length by 12 μ in diameter.

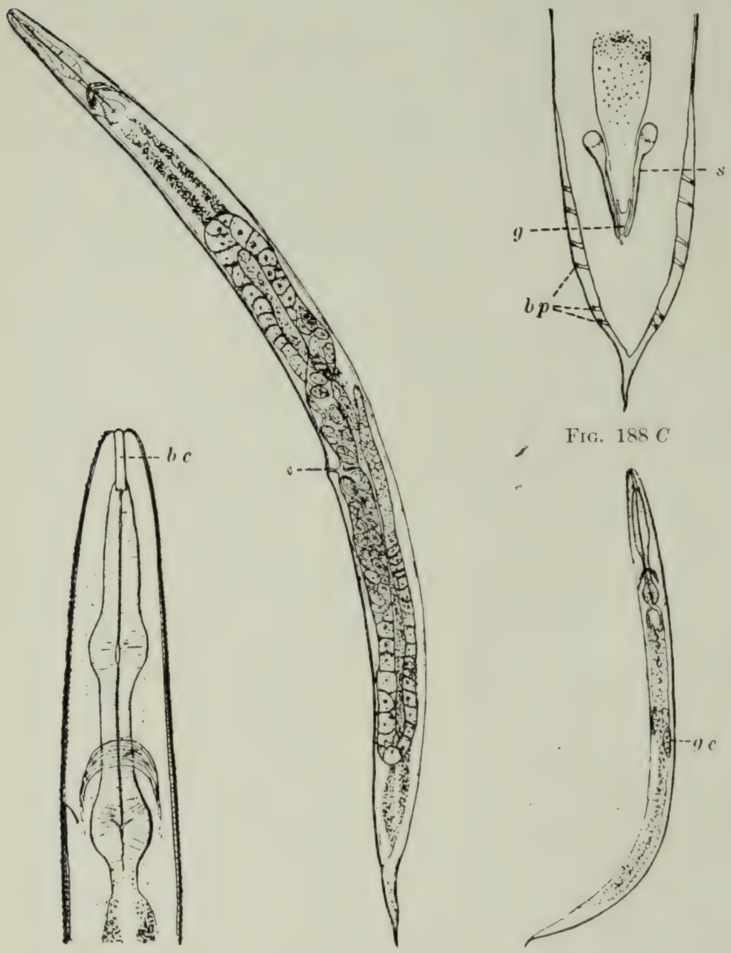

FIG. 188 *C*

FIG. 188 *B* FIG. 188 *A* FIG. 188 *D*

FIG. 188.—*Rhabditis hominis*. *A*, Mature female worm, × 100. *B*, Anterior end of adult worm, × 400. *C*, Posterior end of male showing spicules (*s*), gubernaculum (*g*) and bursa with bursal rays (*bp*), × 400. *D*, Rhabditiform larva, × 300. (After Sandground, Journal of Parasitology.)

and resemble the parent in shape and structure of the esophagus. A genital primordium (*ge*) is found on the dorsal side in the middle of the body. These larvæ are capable of developing into adult worms in a variety of fecal or putrefactive media. In fact evidence

points to the belief that the species is normally free-living and gains entry entirely by accident to the digestive tract of man, where it may remain for a time but where it never becomes a true resident. Contributory to this point of view is the fact that patients harboring the worms are not affected in the least by their presence and that they are evacuated spontaneously without medication. The importance of the species to the clinician rests in the fact that the geographical distribution of the infection is probably similar to that of *Strongyloides stercoralis,* and that the larvæ of these two species may be readily confused. The following differential diagnosis of the two species is taken from Sandground (1925).

Differential Characters of Rhabditis Hominis and the Free-living Phases of Strongyloides Stercoralis.

Rhabditis hominis.	*Strongyloides stercoralis.*
Male.	Male.
Dimensions: 0.9 to 1.3 mm. long; 0.03 to 0.05 mm. broad.	Dimensions: 0.7 to 0.9 mm. long; 0.035 to 0.04 mm. broad.
Buccal cavity: 20 μ long.	Buccal cavity: 13 μ long.
Bursa copulatrix: present, although often inconspicuous.	Bursa copulatrix: absent.
Female.	Female.
Dimensions: 1.4 to 2 mm. long; 0.12 mm. broad.	Dimensions: 1 to 1.2 mm. long; 0.05 mm. broad.
Buccal cavity: same as in male.	Buccal cavity: same as in male.
Reproduction: ovoviviparous.	Reproduction: usually oviparous.
Eggs: 24 to 44 μ by 32 to 28 μ; often arranged in a double row in each uterus; 20 to 50 in number.	Eggs: 42 to 46 μ by 36 to 33 μ; usually arranged in a single row in each uterus, 16 to 18 in number.
Larva (young rhabditiform).	Larva (young rhabditiform).
Dimensions: 0.24 to 0.3 mm. long; 0.12 to 0.03 mm. broad.	Dimensions: 0.2 to 0.25 mm. long 0.016 mm. broad.
Buccal cavity: 15 to 19 μ long.	Buccal cavity: 8 to 10 μ long.
Genital primordium: 22 to 24 μ long.	Genital primordium: 34 to 36 μ long.
This larva always develops into a rhabditiform sexual adult.	This larva develops either into the sexual intermediate rhabditiform generation or metamorphoses directly into the filariform larva.

Genus Turbatrix Peters, 1927.

(genus from τυρβη, crowd and θρίξ, hair).

5. **Turbatrix aceti** (Müller, 1783) Peters, 1927.

Synonyms.—*Vibrio aceti* Müller, 1783; *Anguillula aceti* (Müller, 1783) Müller, 1786; *Gordius aceti* (Müller, 1783) Oken, 1815; *Rhabditis aceti* (Müller, 1783) Dujardin, 1845.

This worm is the common "vinegar eel," which is frequently present in various types of fermenting liquids containing acetic

acid. The worm is cylindrical in shape, with a slight anterior and considerable posterior tapering, and possesses a non-striated transparent cuticula. The male measures 1 to 2 mm. in length by 24 to 40 μ in diameter, has two equal spicules 38 μ long, the shafts of which are more or less completely closed tubes, and in addition, a keel-shaped gubernaculum. It also has two pairs of preanal, one pair of adanal and one pair of postanal papillæ (all ventral), as well as one pair of postanal dorsal papillæ, but it lacks a bursa or alæ. The female measures 2.4 mm. in length by 40 to 72 μ in diameter, and is viviparous, giving birth to rhabditiform larvæ measuring 222 μ long and 12 μ in diameter. Development is direct.

Human cases haboring this worm have all been women, in whose urine or vaginal exudate it has been found. It seems likely that they had been accidentally introduced by women using a vaginal douche of vinegar in which the worms were living. No significant clinical symptoms have been reported.

Family TYLENCHIDÆ Micoletsky, 1922.

The members of this family are free-living saprozoites or parasites on plant tissues. The pharynx in the adult worms is modified into a protrusile spear or onchium. The presence of members of this family in the digestive tract of man is purely accidental.

Genus Anguillulina Gervais and v. Beneden, 1859.
(genus from *anguilla*, eel, or little snake).

6. **Anguillulina putrefaciens** (Kuehn, 1879) Braun, 1895.

Synonyms.—*Tylenchus putrefaciens* Kuehn, 1879; *Trichina contorta* Botkin, 1883.

This species is a common parasite of the bulb of onions. It has been recorded once by Botkin (1883) in the vomitus of a patient who had previously had a meal of onions.

Genus Heterodera Schmidt, 1871.
(genus from ετερος, different and δέρη, neck).

7. **Heterodera radicicola** (Greef, 1872) Mueller, 1884.

Synonyms.—*Anguillula radicicola* Greef, 1872; *Tylenchus radicicola* (Greef, 1872) Oerley, 1880; *Caconema radicicola* (Greef, 1872) Cobb, 1924; "*Oxyuris incognita*" Kofoid and White, 1919.

Heterodera radicicola is a true parasite of plant tissues. It has been described from the roots and stems of dozens of species, many of which are eaten by man. The unmodified worm is a typical tylenchid species with a well-developed onchium or spear in the pharyngeal cavity (Fig. 189). The worm is thread-like in appearance with an average length of 1.6 mm. and a transverse diameter of

30 μ. The anterior and posterior ends taper to a blunt point. There are no alæ. The cuticula is transversely striated. Anteriorly there are six labia, four of which have minute papillæ. The esophagus is a cylindrical organ about 100 μ long, terminating posteriorly in a spherical cardiac bulbus. The intestine lies in the posterior three-fourths of the body, opening through the rectum into the cloaca at its caudal end. The mature male worm is typically rhabditiform in shape. There are two testes, which coalesce posteriorly to form a single tubule which is continuous with the unpaired vas deferens. This canal opens into the cloaca just anterior to the rectal opening. There are two slightly curved copulatory spicules of equal length, measuring 34 to 39 μ, guarding the outer opening of the genital canal. The adult female is pyriform, lemon-shaped or bottle-shaped,

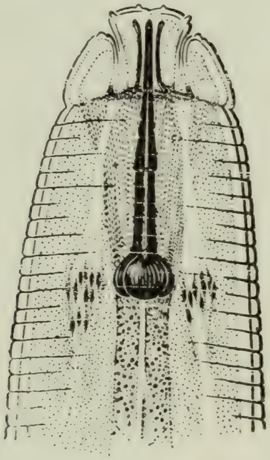

FIG. 189.—Anterior end of *Heterodera radicicola*, greatly enlarged, showing onchium. (After Cobb, Journal of Parasitology.)

and ranges from 0.6 to 0.75 mm. in length by 0.4 to 0.5 mm. in diameter, being broadest in the posterior third. Both the onchium and esophagus are considerably smaller than in the male. The intestine is tremendously swollen to accommodate the large amount of food consumed. The two ovaries are concealed by the food mass, but the converging uteri can be made out by the eggs which they contain. The vulvar opening is only slightly anterior to the cloacal pore. The eggs which are laid by the gravid female measures 82 to 120 μ in length by 24 to 43 μ in breadth, are elongated oval with rounded ends and are either flat or slightly concave on one side. At the time of oviposition segmentation is just commencing but the embryos soon develop by equal cleavage stages successively into morula, gastrula and motile larvæ (Fig. 190, *1–4*). The larva on escaping from the egg-shell measures from 345 to 370 μ in length.

It is readily recognized as a young tylenchid. It may remain and develop in the same roots as its parents, but in case of decay of the host tissues it migrates into the soil, and whenever possible penetrates into a new root, where it begins to consume food ravenously. Upon reaching its full development (*ca* 400 μ in length) it metamorphoses by swelling up, and moulting its skin, sooner or later becoming coiled up inside the newly-formed cuticle. By this time the worm comes to possess differentiating male or female genital organs. It now moults a second time and becomes transformed into an adult worm.

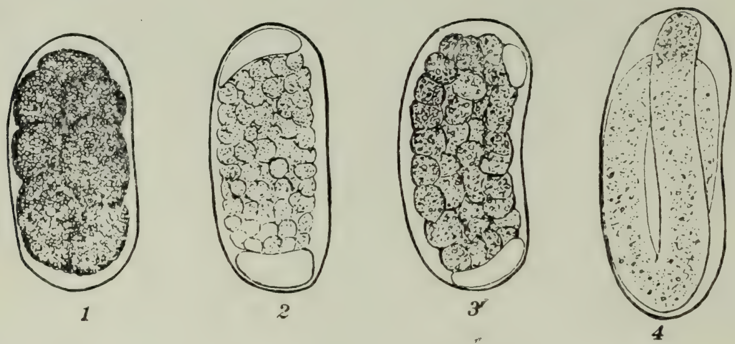

FIG. 190.—Stages in the maturing of the egg of *Heterodera radicicola*. × ca. 400. (After Sandground, Journal of Parasitology.)

The interest of this worm to students of human helminthology lies in the fact that the eggs in parasitized vegetable tissues which are ingested by man are set free in the human digestive tract and are evacuated in the feces, so that fecal examination would seem to indicate the presence of a nematode inhabitant of the human bowel. Sandground (1923) has shown that the eggs designated by Kofoid and White (1919) as "*Oxyuris incognita*" belong to this species of nematode.

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CHAPTER XXV.

THE MYOSYRINGATE NEMATODES (CONTINUED).

STRONGYLOIDEA, TRICHOSTRONGYLOIDEA AND METASTRONGYLOIDEA.

(HOOKWORMS AND RELATED FORMS.)

Suborder Strongylata Railliet and Henry, 1913.

THE species of this suborder consist of forms which are covered with a smooth cuticula. They lack valvular lips; at times the buccal capsule is wanting. There is no distinct cardiac bulbus to the esophagus in the adult worms. The males are bursate, the bursa being supported, typically by six paired and one unpaired radiating ribs. Copulatory spicules are usually two, equal or unequal. There are ordinarily two ovaries. The eggs are thin-shelled, transparent and are in the early stages of segmentation when oviposited. This suborder has three recognized superfamilies, **Strongyloidea** Weinland, 1858, **Trichostrongyloidea** Cram, 1927, and **Metastrongyloidea** Cram, 1927. Of these superfamilies the type superfamily **Strongyloidea** contains the largest assemblage of species, many of which are of considerable economic significance.

SUPERFAMILY STRONGYLOIDEA WEINLAND, 1858.

In this group the buccal capsule is well developed. The males have a broad conspicuous bursa. The females are all oviparous and the eggs on developing give birth to rhabditiform larvæ. No intermediate host is required. These larvæ may directly infect the host without metamorphosis (*Œsophagostomum*, *Syngamus*) or may require a period of feeding followed by transformation into the filariform type before they enter the host (*Ancylostoma*). In the former case the common mode of invasion is passive, *i. e.*, *via* the mouth; in the latter case it is usually active, *i. e.*, *via* the skin or oral mucosa. But mature filariform larvæ of the hookworm may pass through the stomach uninjured and develop directly into adults. Under ordinary circumstances these forms require a period of migration through the portal blood stream before settling down to develop in the air passages (*Syngamus*), or before continuing into the intestinal tract (*Ancylostoma*), where they complete such devel-

opment; but species of *Œsophagostomum,* upon being ingested, pass through the stomach and small intestine directly into the colon, where they burrow into the wall, and complete their larval development, later emerging into the lumen and becoming attached by their heads to the colonic mucosa. The species reported from man belong to three families, **Strongylidæ** Baird, 1853, **Syngamidæ** Leiper, 1912, and **Ancylostomatidæ** (Looss, 1905).

Family STRONGYLIDÆ Baird, 1853.

Species of this family have a conspicuously wide buccal capsule without teeth or cutting plates but with a chitinized corona radiata. The vulva lies in the posterior half of the female's body. The copulatory spicules of the male are well-developed and equal; a bursa is present. Adults of these species are found attached to the digestive tract of their hosts.

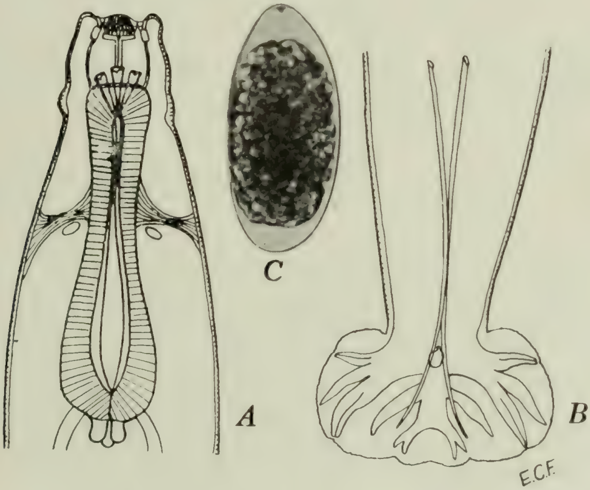

FIG. 191.—*Ternidens diminutus.* *A*, anterior end of body, showing buccal armature and esophagus; *B*, posterior end of male, showing spicules and bursa. × 40. *C*, photomicrograph of egg by Dr. J. H. Sandground. × 450. (*A* and *B* adapted from Railliet and Henry, in Brumpt, Précis de Parasitologie.)

GENUS TERNIDENS RAILLIET AND HENRY, 1909.
(genus from *ter* thrice and *dens,* tooth).

8. **Ternidens deminutus** (Railliet and Henry, 1905) Railliet and Henry, 1909.

Synonyms.— *Triodontophorus deminutus* Railliet and Henry, 1905. *Globocephalus macaci* Smith, Fox and White, 1908.

This species was first described by Railliet and Henry from two specimens, male and female, obtained by Monestier, a surgeon of the

French marine, at autopsy of an African negro in 1865 (habitat, Mayotte). Other cases have been reported by Leiper from natives of Nyasaland and from Portuguese East Africa, and by Noc and Barrois as well as by Brumpt from macaques. Grossly these worms are apt to be confused with ancylostomes, but they can readily be distinguished from the latter species by the position and structure of the oral capsule, which, in *Ternidens*, is terminal and is guarded by a corona of stout bristles. The worms are cylindroid, with a truncated anterior end (Fig. 191*A*). The buccal capsule is subglobose and has on its innermost aspect three complex teeth arising from three lobules of the pharynx. The corona radiata is double. The males measure 9.5 mm. in length by 0.56 mm. in diameter. Subcaudally they are slightly attenuated, while the posterior extremity is drawn out into a flange-shaped bursa (Fig. 191*B*), with characteristic rays. The margin of the bursa is delicately serrated. The spicules are long stout bristles, measuring approximately 0.9 mm. in length. The females measure 12 to 16 mm. long by 0.65 to 73 mm. in diameter. The vulva forms a distinct protuberance a short distance in front of the anal opening. The transparent oval eggs measure 60 by 40 μ. The life cycle and clinical aspects of the infection have not been studied.

GENUS ŒSOPHAGOSTOMUM MOLIN, 1861.
(genus from οἰσοφάγος, esophagus and στομα, mouth).

9. **Œsophagostomum apiostomum** (Willach, 1891) Railliet and Henry, 1905.

Synonyms.—*Sclerostomum apiostomum* Willach, 1891; *Strongylus aculeatus* v. Linstow, 1879; *Œsophagostomum brumpti* Railliet and Henry, 1905.

This species is a common parasite of the large intestine of the gorilla, the orang-outang, and the macaque in West Africa. It is also present in monkeys in the Philippines and in China. It has been reported from man in Northern Nigeria, where 4 per cent of the prisoners in jails harbor the parasites and from Lake Omo, East Africa. The worms are covered with a transversely striated cuticula which is dilated anteriorly between the excretory pore and the mouth (Fig. 192*A*) to form an ovoid swelling, which is more pronounced on the ventral than on the dorsal aspect. The mouth is surrounded by six circumoral papillæ, two lateral and four submedian, visible under low magnification. More central in position there is a corona radiata composed of twelve pyramidal setæ directed anteriad. Within the oral cavity there are three minute recurved teeth, each arising from one of the three lobules of the pharyngeal atrium. The esophageal chamber is tripartite. The males measure 8 to 10 mm. in length by 0.3 to 0.35 mm. in diameter and have a

campanulate bursa with supporting rays arranged as in the accompanying diagram (Fig. 192*B*). The copulatory spicules are long

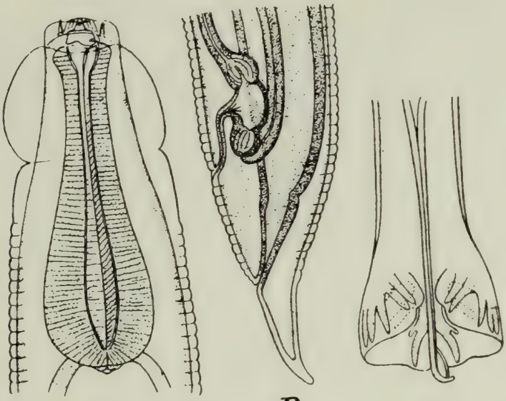

FIG. 192.—*Œsophagostomum apiostomum.* *A*, anterior end of worm; *B*, posterior end of male; *C*, posterior end of female. × 80. (After Railliet and Henry, in Brumpt, Précis de Parasitologie.)

and somewhat curved posteriorly. The females measure 8.5 to 10.5 mm. in length by 0.295 to 0.325 mm. in breadth. The vulvar

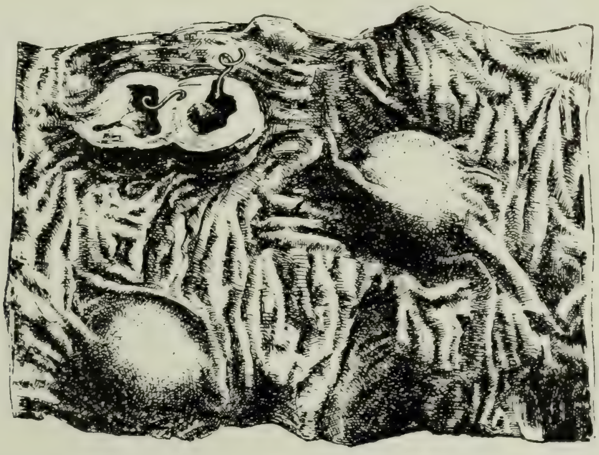

FIG. 193.—Intestinal tumors, with immature *Œsophagostomum apiostomum* in cavities of nodules. Natural size. (After Brumpt, Précis de Parasitologie.)

opening is immediately preanal in position (Fig. 192 *C*). The eggs closely resemble those of the hookworm; they measure 60 to 63 μ by 27 to 40 μ.

The life cycle of the worms of this species probably parallels that of other species of the genus, which have been elucidated. The larvæ (mature ensheathed rhabditiform stage) are swallowed, pass undigested through the stomach and small intestine, and, on arrival in the cecum, exsheath and invade the wall, where they provoke nodule formation (Fig. 193). The larvæ mature in the lumina of these nodules, whereupon they break out into the intestinal lumen, become attached to the mucosa and develop to maturity.

Pathogenicity and Symptomatology.—Information is very meager concerning the clinical aspects of this infection in man. In monkeys the larvæ on invading the wall of the cecum produce an ecchymosis around each motile encysted larva. The cysts which develop around the larvæ are tumorosities of host tissue, consisting of an inner zone of lymphocytes and polymorphonuclear leukocytes surrounded by fibrous connective tissue, lying in the submucosa or muscularis. Upon completing larval development, the worms, which resemble the adult stage except for their smaller size and the absence of sexual organs, cause a rupture of the cysts. This may result in hemorrhage of the adjacent bloodvessels and produce dysenteric symptoms, or may rupture through to the body cavity and produce peritonitis. Secondary invasion of the tumor cavities may set up a septicemia.

Diagnosis.—Practically impossible *ante-mortem*, since the ova resemble those of the hookworm.

Therapeusis.—In endemic areas and other regions where this infection is prevalent in reservoir hosts the patient should be treated with thymol, oil of chenopodium or carbon tetrachloride, which are specific anthelminthics for the adult worms.

Prophylaxis.—Care should be taken not to come in contact with food, water or earth likely to be contaminated with feces of monkeys which commonly harbor the parasite. If Brumpt's hypothesis is correct, danger of infection *via* the skin is as serious as *per os*.

10. **Œsophagostomum stephanostomum** var. **thomasi** Railliet and Henry, 1909.

This species has been recorded once by Thomas from the large and small intestine of man in Manãos, Brazil. The corona radiata of the buccal capsule has a complement of 38 leaflets. The immature males recovered measure 17 to 22 mm. in transverse diameter. The copulatory spicules are slightly curved at the tip. Immature females measure 16 to 20 mm. in length by 0.9 mm. in breadth and end posteriorly in a short conical appendage. The worm is distinguished in several minor points from *Œsophagostomum stephanostomum* Stossich, 1904, taken from the large intestine of the gorilla.

Pathogenicity and Symptomatology.—In the single case on record 187 nodules were found imbedded in the wall of the ileum, cecum and

colon. Each contained a single immature male or female worm. The formation of fibrous connective tissue in the vicinity of the nodules had been sufficient to reduce considerably the capacity of the bowel.

Diagnosis.—Unstudied.

Therapeusis.—Unstudied.

Prophylaxis.—Probably the same as for other species of this genus having monkeys and other primates as reservoir hosts.

Family SYNGAMIDÆ Leiper, 1912.

The adult worms of this family are typically joined in copula. In the type genus *Syngamus* this union is permanent. They possess a large, thick-walled buccal capsule, which is armed at its inner base with 6 to 9 teeth of two distinct sizes. The bursa and supporting rays of the male are characteristically those of the superfamily. In the genus *Syngamus* the spicules are short and thick, and the vulva is situated in the anterior part of the female's body. The eggs are provided with a cap at each pole.

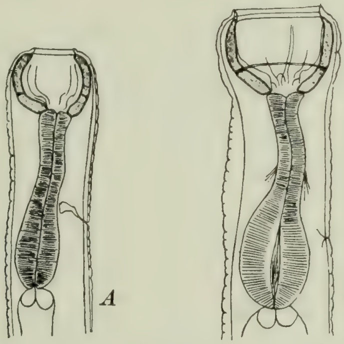

Fig. 194.—Anterior ends of *Syngamus kingi; A*, male worm; *B*, female worm. Enlarged. (After Leiper, Trans. Royal Soc. of Med. and Hyg.)

Genus Syngamus v. Siebold, 1836.
(genus from συν, together and γαμος, marriage).

11. **Syngamus kingi** Leiper, 1913.

A pair of syngamid worms in copula was discovered by King in January, 1913 in the sputum of an Irish woman of St. Lucia, West Indies. The pair differ from the previously described species of the genus *Syngamus* in the following respects: The buccal capsules of male and female worms (Fig. 194 *A, B*) lie in the same transverse level instead of being at different levels; they open directly anteriad instead of dorsad as in *S. trachea* (Montagu, 1811). In his description of the species Leiper failed to record the actual or relative sizes

of the members of the pair, but by inference from other related specimes the female is from two and a half to four times as large as the male. The eggs are not described or figured by Leiper.

Nothing is known of the life history or pathogenicity of *Syngamus kingi.* It is suggested that the infection in man is accidental and that probably some feline is the natural host. In *Syngamus trachea* of the domestic fowl the adult worms live in the bronchi and trachea of the host. Here the eggs (Fig. 195*A*) are laid, are coughed up and swallowed, pass out in the feces and develop in moist earth. By the eighth or ninth day the embryos are fully developed into infective larvæ, break out of the egg-shell through the polar caps, and are ready for ingestion by the next host. Either eggs containing the fully matured larvæ or the hatched embryos are infective. Upon being swallowed they become active and migrate through to the lungs where they are found twenty-four hours after ingestion. In the course of a week or shortly afterward they have paired in the bronchioles, pass out to the larger air passages and attach themselves to the mucous membrane of the bronchi or trachea, where they become sexually mature within three weeks after infection.

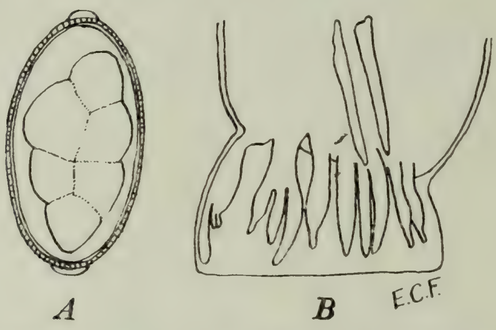

Fig. 195.—*Syngamus trachea.* *A*, egg, × 380; *B*, posterior end of male worm, showing spicules and bursal rays, enlarged. (After Ortlepp, Journal of Helminthology.)

The species *Syngamus bronchialis* in geese, *S. trachea* in domestic fowls and turkeys, and *S. laryngeus* in cattle, as the causal organisms of "gapes," are of considerable economic importance.

Family ANCYLOSTOMATIDÆ (Looss, 1905) Lane, 1917.

The species of this family are popularly known as "hookworms." This designation is due to the development of cutting organs on the ventral side of the oral aperture, which, in the subfamilies **Ancylostomatinæ** and **Strongylocanthinæ**, consist of tooth-like processes, and in the subfamily **Necatorinæ**, of semilunar plates. The human representatives of the family belong to the genera *Ancylostoma* and *Necator.*

GENUS ANCYLOSTOMA DUBINI, 1843.
(genus from *αγχύλος*, hook and *στόμα*, mouth).

12. **Ancylostoma duodenale** (Dubini, 1843) Creplin, 1845.

Synonyms.—*Agchylostoma duodenale* Dubini, 1843; *Anchylostomum duodenale* (Dub., 1843) Diesing, 1845; *Anchylostoma duodenale* (Dub., 1843) Chiaje, 1846; *Strongylus quadridentatus* v. Siebold, 1851; *Dochmius ankylostomum* Molin, 1860; *Sclerostoma duodenale* (Dub., 1843) Cobbold, 1864; *Strongylus duodenalis* (Dub., 1843) Schneider, 1866; *Dochmius duodenalis* (Dub., 1843) Leuckart. 1867; *Uncinaria duodenalis* (Dub., 1843) Railliet, 1885.

Historical.—*Ancylostoma duodenale,* the "Old World hookworm," is, more correctly speaking, the autochthonous human hookworm of the north temperate zone of the Eastern Hemisphere. Although undoubtedly an important cause of disease in ancient times, and probably referred to in the Eber's papyrus (1600 B.C.), the first authentic records of the worm and the disease for which it is responsible, were those of the Arabian physician, Avicenna (980–1037 A.D.). The first accurate description of the worm with a Linnean designation was published by Dubini in 1843, from specimens obtained at the autopsy of a Milanese woman in 1838. In 1878 Grassi and Parona demonstrated that the presence of the worm in the bowel could be diagnosed by the recovery of the ova passed in the feces. In 1880 Perroncito published his findings on the development of the free-living rhabditiform and filariform stages of the worm, while Leichtenstern (1886–1887), following Leuckart's experimental work on *Rhabdias bufonis,* found that the "encysted motile larvæ (of *Ancylostoma*), at a certain period and stage of their development, when introduced into the human intestinal tract, are capable of developing there into mature *Ancylostoma.*" Following this Looss (1896–1897), first by accidental infection of himself with *A. duodenale* and later by experimental demonstration with *A. caninum* in the dog, discovered that the common method of infection with the mature filariform stage of the hookworm was dermal, and that these larvæ, after penetrating through the skin, follow an indirect route of migration to the intestine, *via* the venous system to the lungs, thence out into the air passages and over the epiglottis into the intestinal tract.

Structure of the Adult Worms.—The mature worms (Fig. 196 *A, B*) are cylindrical in shape, roseate-white or ivory-gray in color, slightly narrowed anteriorly, and have the anterior end directed somewhat dorsad. The males measure 8 to 11 mm. in length by 0.4 to 0.5 mm. in breadth and the females measure 10 to 13 mm. in length by 0.6 mm. in breadth. The buccal capsule (Fig. 192) is very heavily impregnated with a chitin-like substance. The cavity is oval in shape, the transverse diameter being the longer. The outer

FIG. 196.—Adult *Ancylostoma duodenale;* *A*, male; *B*, female. × 20. (Adapted from Looss.)

part of the capsule is made up of articulated grooved portions; the inner part, save for the dental armature, is smooth and unarticulated. Ventrally there is a pair of articulated dental plates, each consisting

of two large teeth solidly joined together, of which the outer is somewhat the larger. The cuticula is infolded into the mouth cavity but is pierced by the teeth. Dorsally there is a plate with a deep median cleft, the two free ends projecting slightly over the edge of the mouth. Just within this plate is the orifice of the dorsal gland. In the depth of the capsule there is a pair of internal teeth. Ventrolateral to each outer tooth are the openings of the pair of ducts from the cephalic glands, which extend posteriad as far as the mid-plane of the body. Their function is probably histolytic. The esophagus is the direct internal continuation of the buccal cavity. Its length is about one-sixth that of the entire worm. It is lined with a chitin-like substance. It is somewhat swollen posteriorly and is guarded at its posterior exit by a trilobed cardiac valvular apparatus. Within the wall of the esophagus there are three glands, one dorsal and two subventral. The intestine proper (chyle intestine or mid-

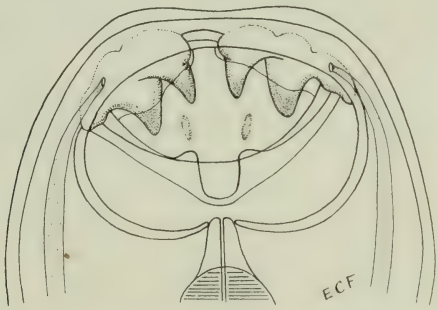

FIG. 197.—Anterior end of *Ancylostoma duodenale*, showing dental pattern. × 240. (Original.)

intestine) is the non-chitinized portion of the digestive tube which continues through the greater portion of the worm and joins posteriorly the short chitinized rectum. The food of the hookworm consists essentially of the mucous membrane of the host's intestine. Upon becoming attached to host tissue the worm seizes one or more of the villi (Fig. 198) triturating and gradually sucking in the substance, thus eventually consuming all of the villi around the head of the parasite. Frequently small capillaries running into the villi become involved so that blood is also taken into the digestive tract of the worm.

The excretory pore is mid-ventral in position, just behind the nerve ring. The excretory vesicle is a complex structure with branches and ramifications, embracing the ventral side of the esophagus and involving a "carrying cell," and a "suspensory cell." Intimately connected with the excretory apparatus are the so-called cervical glands, a pair of elongated non-glandular cells on the ventral side of

the body, extending backward some distance behind the esophagus and opening through efferent ducts into the excretory canal system. The excretory canals are imbedded in the lateral-line-complex all the way from the buccal capsule to the subcaudal region of the body.

Fig. 198.—Section through human intestine, showing method of attachment of hookworm to the wall; *L*, leukocytic infiltration; *B*, bloodvessel; *MM*, muscularis mucosæ; *DK*, intestinal glands; *E*, epithelium; *EL*, submucosa. Enlarged. (After Oudendal, in Transactions of Fifth Biennial Congress of Far Eastern Association, Courtesy of John Bale Sons & Danielsson, Ltd., London.)

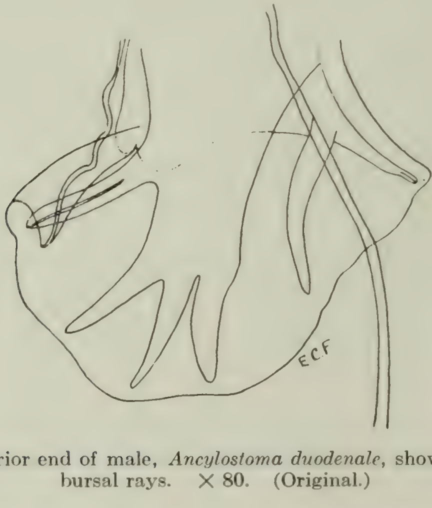

Fig. 199.—Posterior end of male, *Ancylostoma duodenale*, showing spicules and bursal rays. × 80. (Original.)

The male worm (Figs. 196*A*, and 199) is provided with a campanula-shaped bursa which gives an expanded appearance to its

caudal extremity. The bursa is supported by fleshy rays, the pattern of which is characteristic for the species. The male genital apparatus, if fully extended, would measure more than twice the length of the body. The inner blind end of the testis begins a little behind the origin of the cement gland. As the tubule proceeds forward it becomes wrapped in transverse coils around the mid-intestine. Upon reaching the posterior aspect of the cervical gland a longitudinal loop extends forward for some distance, after which the tubule again proceeds posteriad as the seminal duct in transverse coils to the middle of the body, there to expand into the elliptical vesicula seminalis. This latter organ opens posteriad into the ejaculatory duct, which is closely approximated on either side by the pair of large multicellular cement glands, so that the duct and the glands form a supporting trough for the intestine. This structure continues to the subcaudal region of the worm, where the ejaculatory duct, now chitinized, enters the rectum, which immediately passes into the cloaca. The two spicules are long bristle-like structures (1.9 to 2 mm. in length) each lying in a tubular cavity ventro-lateral to the ejaculatory duct. They are regulated by retractor and exsertor muscles and by the gubernaculum which is situated in the dorsal wall of the cloaca and spicular canal.

The female genital organs (Fig. 196*B*) consist of two very long ovarian tubules, one coiled back and forth in the prevulvar portion of the body and one in the postvulvar part. As they approach the vulva the tubules become appreciably reduced in diameter and proceed for a short distance as oviducts. Farther outward they become successively differentiated into the seminal receptacles, the uteri and the ovejectors, the two horns finally joining to form the vulva. In *Ancylostoma duodenale* the vulva opens to the outside at the beginning of the posterior third of the body. Copulating pairs of worms are frequently seen in which the bursa of the male is applied to the vulva of the female, the position being maintained by the insertion of the copulatory bristles into the vulva and by the cementum elaborated by the cement glands of the male and deposited between the vulva and the bursa.

Description of the Eggs and Larvæ.—The eggs on leaving the body of the female worm are in the early stages of segmentation. They are oval, with bluntly rounded ends and with a transparent hyaline shell-membrane, which is so thin as to appear as a single line under low power of the microscope. While there is considerable variation in their size, they average 60 by 40 μ (Fig. 263 *V*). When evacuated in the normal stool they are in the two- to eight-cell stages of segmentation. Occasionally unsegmented eggs are found in feces, while in constipated stools that have remained several days in the bowel gastrulæ and even unhatched rhabditiform larvæ may be present. As long as the eggs remain in undiluted night-soil very

little development takes place, but on dilution of the feces with earth, such as occurs when the night-soil is placed on the land for fertilizer or where natural deposits of egg-containing feces are made on moist earth, development proceeds rapidly, so that under favorable conditions of temperature hatching takes place in twenty-four to forty-eight hours. The optimum conditions for the hatching of eggs of *A. duodenale* appear to be moist aërated soil, protected from the direct rays of the sun, with an average temperature of about 25° C. Excess of water, of acidity, or of sunlight hinders hatching and development.

Fig. 200. — Rhabditiform larva of *Ancylostoma duodenale*. × 310. (Adapted from Looss.)

The larva emerging from the egg is a typical rhabditiform nematode (Fig. 200), measuring 0.25 to 0.3 mm. in length, bluntly rounded anteriorly and attenuated posteriorly. The cuticular lining of the narrow buccal cavity is thickened and is modified into an appreciable annulus just in front of the esophagus. The esophagus occupies the anterior third of the digestive tract; it is composed of a cylindrical anterior portion and a pyriform posterior bulbus. The anal opening is situated at the beginning of the caudal fifth of the body. After about three days active feeding and growth the larva moults, increasing in size up to 0.5 mm. during this second stage, but still retaining its rhabditiform character. At the beginning of about the fifth day the larva ceases feeding, the mouth becomes closed, the esophagus elongates, and moulting occurs again, although the larva usually remains within the shed cuticula, which becomes shrunken but remains attached at the oral and anal ends. The quiescent larva which results from this metamorphosis (Fig. 201*A*) is the filariform type; this is the infective stage for man. Under optimum conditions these larvæ are viable in the soil up to fifteen weeks. They can be differentiated from the similar stage of *Necator americanus* (Fig. 201*C*) in that (1) the protrusile pharyngeal spears are unequal in thickness in *Ancylostoma* (Fig. 201*B*) and equal in *Necator* (Fig. 201 *D*), and (2) the cardiac portion of the esophagus appears to be in direct contact with the anterior portion of the chyle intestine in *Ancylostoma* while in *Necator* an intermediate transverse space appears to be present. After a period of quiescence or upon the loss of the enveloping moulted cuticula the larvæ become active again, and, on contact with the human skin, penetrate

the skin layers, sooner or later reaching a bloodvessel, whereupon they are carried through the right heart to the lungs, thence after breaking out into the alveoli, migrate up the air passages to the epiglottis and down the intestinal tract to the ileum, where they

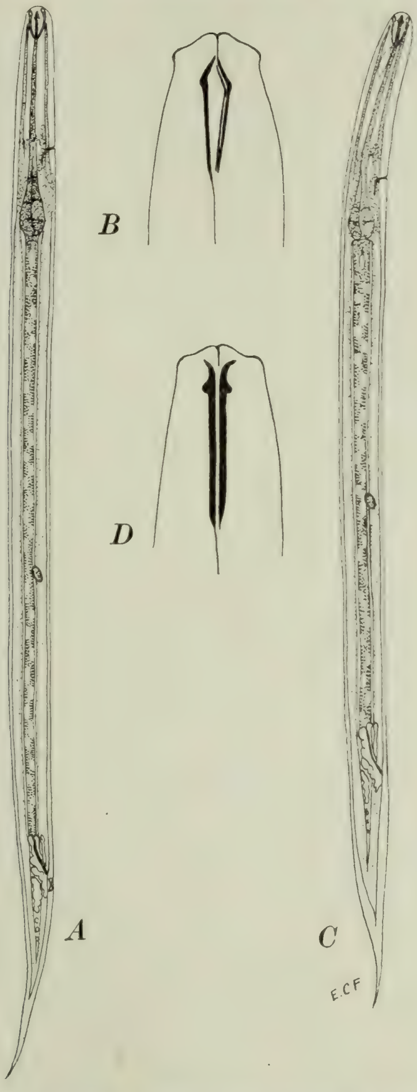

FIG. 201.—Filariform larvæ of human hookworms; *A*, *Ancylostoma duodenale.* × 160. (Original adaptation from Looss.) *B*, head of *A. duodenale* enlarged 1330 times to show buccal spears. (After Heydon, Medical Journal of Australia.) *C*, *Necator americanus.* × 160. (Original adaptation from Looss.) *D*, head of *Necator americanus* enlarged 1330 times to show buccal spears. (After Heydon, Medical Journal of Australia.)

become attached, mature and mate. About five weeks is required from the entry of the filariform larvæ into the skin until egg-laying begins. Mature females of *Ancylostoma duodenale* lay about two to two and a half times as many eggs per day as do the females of *Necator americanus*.

Factors Involved in the Growth of Eggs and Larvæ.—In the undiluted feces few or no larvæ are produced since the high degree of acidity developing there (pH 4.8 to 5) is very unfavorable for growth. In tropical countries, however, rains and insects operate so as to dilute or disseminate the fecal deposits. Water not only serves as a vector but in diluting or moistening the feces serves to initiate hatching and growth of the larvæ. However, rapidly moving water is not conducive to development, and heavy rainfall such as occurs in the tropics is a natural sterilizing agent for infected areas. Water covering soils containing large numbers of hookworm larvæ tends to cause rapid death of the larvæ on account of the growth of bacteria, fungi and protozoa which are larvicidal. Alternating drying and moistening of the medium tend to kill the larvæ.

Temperature is an important conditioning factor of growth. While 27° C. seems to be favorable to hatching and development, at this temperature most of the larvæ succumb in nine weeks, although as many as 5 to 10 per cent may survive some weeks longer; at 35° C. the majority die in four weeks; at 15° C. growth is slower and the length of life longer. At 0° C. growth is inhibited and death occurs fairly rapidly. Within certain limits the viability of hookworm larvæ in a favorable environment varies inversely as the rate of metabolism. Direct sunlight of the tropics is distinctly unfavorable for hookworm larvæ in the soil. Dense shade constitutes the optimum for their development and continued existence. In light shade the period of viability is reduced.

Dilution of the feces with soil is highly favorable to hatching and development. Larvæ have been found to migrate to the surface after having been buried in sandy loam to a depth of 36 inches. Mixtures of clay reduce the range of migration directly with the proportion of this ingredient in the soil. Normally in fecal deposits on the surface of the soil the greatest number of hookworm larvæ remains in the upper ½ inch of the soil and the number decreases rapidly with the increasing depth of the soil. They do not migrate out of the soil onto vegetation in the immediate vicinity.

It was formerly believed that the second ecdysis occurred only at the time of human infection. But in the tropics, a large share of the larvæ becomes unsheathed in the soil and lives for the normal length of time. It was also formerly believed that larvæ might live in the soil for long periods of time, possibly years and still remain active (*i. e.*, viable). Under tropical conditions seven or eight weeks appear to be the maximum period of existence. In temperate

zones this period is increased as the metabolism of the larva is slowed down. In regions where ancylostomiasis is most prevalent the disease is probably propagated through constant reinfection of the soil, rapid development of the larvæ, and consequent reëxposure of human beings frequenting such infected spots.

The length of life of the adult worms of this species has been estimated at nine to ten years but recent investigations indicate that this estimate is probably too high. Natural elimination of an infection where no reinfection takes place may occur within five or six years. Man is probably the only normal definitive host of this species, although Baylis and Daubney (1923) record a single female worm from a tiger (Calcutta).

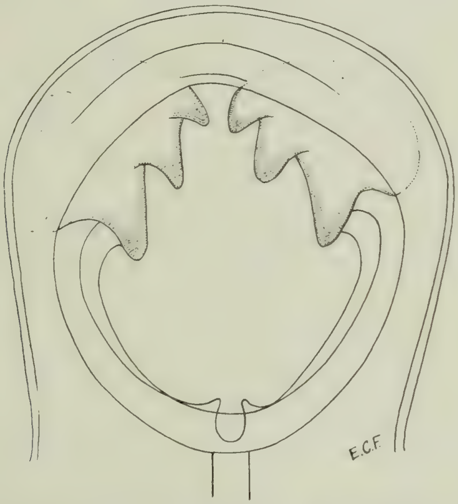

FIG. 202.—Anterior end of *Ancylostoma caninum*, showing dental pattern. × 240. (Original.)

13. **Ancylostoma caninum** (Ercolani, 1859) Hall, 1913.

Synonyms.—*Sclerostomum caninum* Ercolani, 1859; *Strongylus caninum* Ercolani, 1859; *Uncinaria canina* (Erc., 1859) Railliet, 1900.

This is the common hookworm of the dog and cat. It is practically cosmopolitan in distribution, but is more properly autochthonous in the Holarctic region, being replaced, at least in part, in the more tropical areas by *A. braziliense*. It is questionable whether it occurs as a parasite of the human host. The male worm averages 10 mm. in length by 0.4 mm. in breadth and the female, 14 mm. in length by 0.6 mm. in breadth. The buccal capsule (Fig. 202) is the widest and has the largest orifice of any described species of the genus. Each of the two ventral dental plates carries three teeth, of which the innermost is the smallest and the outermost

the largest. The bursa is large and flaring and is supported by typically long and slender rays. The copulatory bristles are stout and relatively short. The eggs are similar in type to those of *A. duodenale,* but are slightly larger, measuring 63.8 by 40.4 μ. The life cycle is similar to that of *A. duodenale,* but *A. caninum* is adapted to a somewhat cooler free-living *milieu* than *A. duodenale.*

The infective filariform larvæ of *A. caninum* are probably capable of producing a mild transient dermatitis when brought in contact with the human skin.

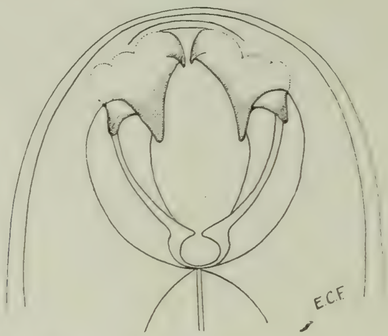

FIG. 203.—Anterior end of *Ancylostoma braziliense,* showing dental pattern. × 240. (Original.)

14. **Ancylostoma braziliense** Gomez de Faria, 1910.

Synonym.—*Ancylostoma ceylanicum* Looss, 1911; (larva) *Agamonematodum migrans* Kirby-Smith, Dove and White, 1926.

This species of *Ancylostoma* was first found by Gomez de Faria in dogs and cats in Southern Brazil in 1910 and was described by Looss the following year from a human infection in Ceylon. Since that time its presence has been recorded in a number of instances from man, the dog and the cat in the Oriental region (man, in the Philippines, Malay, Java, Sumatra, Siam, Burma, Bengal and Fiji; the dog in Ceylon, the Philippines and South China; the cat, in the Philippines and Formosa); also from the dog in Zanzibar, Panama, British Guiana, Florida and Texas; and from the leopard in Sierra Leone. In human cases it is usually a minor infection along with *Necator americanus;* in dogs and cats it is frequently found in a predominantly *Ancylostoma caninum* infection. The male worm measures 7.75 to 8.5 mm. in length by 0.35 mm. in breadth and the female, 9 to 10.5 mm. by 0.375 mm. The buccal capsule (Fig. 203) differs from that of *A. duodenale* in having a somewhat smaller aperture, while the dental plates each carry a small curved anterior tooth and two large posterior ones. The bursa of the male also differs in being smaller, in being almost as broad as long, and in having short stubby rays. The eggs are indistinguishable from those of

A. duodenale. The investigations of Kirby-Smith, Dove and White (1925–1928) have shown that mature filariform larvæ of this species are more frequently viable by the oral than by the skin route of invasion; and that larvæ entering the human body *via* the skin are responsible for "creeping eruption" in the Southern United States. (For clinical aspects of this infection see section on "Pathogenicity and Symptomatology of Hookworm Disease.")

15. **Ancylostoma malayanum** (Alessandrini, 1905) Lane, 1916.

Synonym.— *Uncinaria malayana* Alessandrini, 1905.

This species of hookworm was first described by Alessandrini (1905) from the Malay bear (*Helarctos malayanus*). In 1916 Lane reported the same worm from the Himalayan bear (*Ursus torquatus*). Yorke and Maplestone (1926) record this worm from man. The males measure 12 to 15 mm. long by 0.6 mm. broad; the females, 15 to 19 mm. long by 0.6 mm. broad. Thus the species is the longest and comparatively the most slender of the described species of the genus. The buccal capsule is similar to that of *A. duodenale* but is appreciably smaller. The inner tooth on each ventral dental plate is similar to that of *A. duodenale;* the outer tooth is longer, more acuminate and narrower at its base. The bursa of the male is large and the rays fairly stout. The terminal parts of the dorsal ray are noticeably sinuous. The copulatory spicules are very long (3 mm.) and delicate. The eggs are indistinguishable from those of *A. duodenale.*

Genus Necator Stiles, 1903.
(genus from *neco,* to kill).

16. **Necator americanus** (Stiles, 1902) Stiles, 1906.

Synonyms.— *Uncinaria americana* Stiles, 1902; *Ankylostomum americanum* (Stiles, 1902) v. Linstow, 1903; *Ancylostoma americanum* (Stiles, 1902) Siccardi, 1905; *Necator africanus* Harris, 1910; *Necator argentinus* Parodi, 1920; (?) *Necator suillus* Ackert and Payne, 1922.

This species of hookworm, commonly designated as the "New World hookworm" was described as a new species by Stiles in 1902 from material sent him for examination by Allan J. Smith from Galveston, Texas. Investigation soon showed that this species was the prevalent form in the Southern United States, the Caribbean littoral, Central and South America. Later it was found that it was also the common autochthonous species in the Eastern Hemisphere south of 20 degrees north latitude.

Necator americanus belongs to the hookworm subfamily **Nectorinæ**, distinguished by the presence of semilunar plates and lacking the dental processes characteristic of the buccal capsule of the **Ancylostominæ**. The genus *Necator* is further characterized by

having in the depth of the buccal cavity two triangular subventral lancets and two subdorsal ones.

Necator americanus is grayish-yellow in color, with an occasional reddish cast. The body is cylindrical, and somewhat attenuate anteriorly. The male measures 7 to 9 mm. in length by 0.3 mm. in breadth; the female, 9 to 11 mm. in length by 0.4 mm. in breadth. The anterior end of the worm is strongly reflexed dorsad. The buccal capsule (Fig. 204) is conspicuously small. On the ventral aspect there are two semilunar cutting plates while on the dorsal side there is a pair of slightly developed lips. A conical dorsal median tooth projects prominently into the buccal cavity. The lancets in the depth of the cavity are of the type described for the genus. This type of biting apparatus is structurally inferior to that

FIG. 204. — Anterior end of *Necator americanus*, showing oral armature. × 400. (Original.)

FIG. 205.—Posterior end of male *Necator americanus*, showing spicules and bursal rays. × 80. (Original.)

of the members of the genus *Ancylostoma*. The caudal bursa of the male (Fig. 205) is bilaterally symmetrical; it is long and wide. The rays consist of a small dorsal pair, bipartite at their tip; a slender dorso-lateral pair; a large fleshy bifurcate lateral pair, with a large ventro-lateral arising from each lateral; and a cleft ventral pair arising from the inner aspect of the lateral. The two copulatory spicules are long and slender. The distal tip of each is typically provided with a delicate barb. The outer ends of the two spicules with their barbs are frequently fused. The vulva, of the female is in the middle of the body or slightly anterior to it. The eggs are transparent and thin-shelled, and are slightly narrower and longer (64 to 76 by 36 to 40 μ) than those of *Ancylostoma duodenale*. The worms live in the small intestine of man, the chimpanzee, the gorilla, the pig (?), the rhinoceros, and occasionally the dog. The life

cycle of this species is similar to that of *Ancylostoma*, although *Necator* is typical adapted to a warmer free-living environment than is *A. duodenale*.

Nosogeography and Ethnological Distribution of Hookworm Disease. (Fig. 206).—The problem of the geographical distribution of human hookworms is an almost new field of investigation. It involves two important critical factors: (1) the areas of land in which climatic conditions are favorable for the growth of the free-living phase of the life cycle of the hookworm in the soil; and (2) the actual incidence of infection of the several species (for practical purposes the two species, *Ancylostoma duodenale* and *Necator americanus*), in indigenous (autochthonous) populations practically or entirely free from foreign contact. The former condition of the environment is usually described as being delimited by those isothermic belts where freezing temperatures do not occur for any considerable part of the year. In the United States this line is usually considered the northern boundary of North Carolina and its extention further west. In general the infective zone is limited by 35 degrees north latitude and 30 degrees south latitude, although there are temperature exceptions to this limit, as for example warm mines in colder climates (Wales, Central and Northern Europe, California, Illinois, China), and other regions where the sanitary conditions within the homes, such as dirt floors and defecation within the houses, tend to perpetuate the life cycle during winter months. There are, however, large stretches of desert within the thermally potential areas where desiccation prevents the development of the extra-human phases of the life cycle. There are also areas outside of these zones where a minimum infection is harbored, although it is not clinically important.

The original distribution of *Ancylostoma duodenale* and *Necator americanus* is known to have varied considerably from that of its present location. This has been brought about primarily by the migrations of peoples. Due to this cause the parasitic (hookworm) index of certain peoples has been entirely modified. Our present information, which has been collected from various sources, mostly by Darling (1920), leads us to believe that the original distribution of the hookworms was entirely in the Eastern Hemisphere, and that *Ancylostoma duodenale* occurred north of 20 degrees north latitude and *Necator americanus* south of 20 degrees north latitude. Thus the ancylostome species existed in Europe and parts of Africa bordering on the Mediterranean; in Northern India, Central and North China and Japan. *Necator* was found in Tropical and South Africa, Southern India, the Malay, Java, Borneo, Celibes. New Guinea, Fiji and other islands of the Polynesian and Micronesian group, Siam, French Indo-China and to a certain extent in southernmost China.

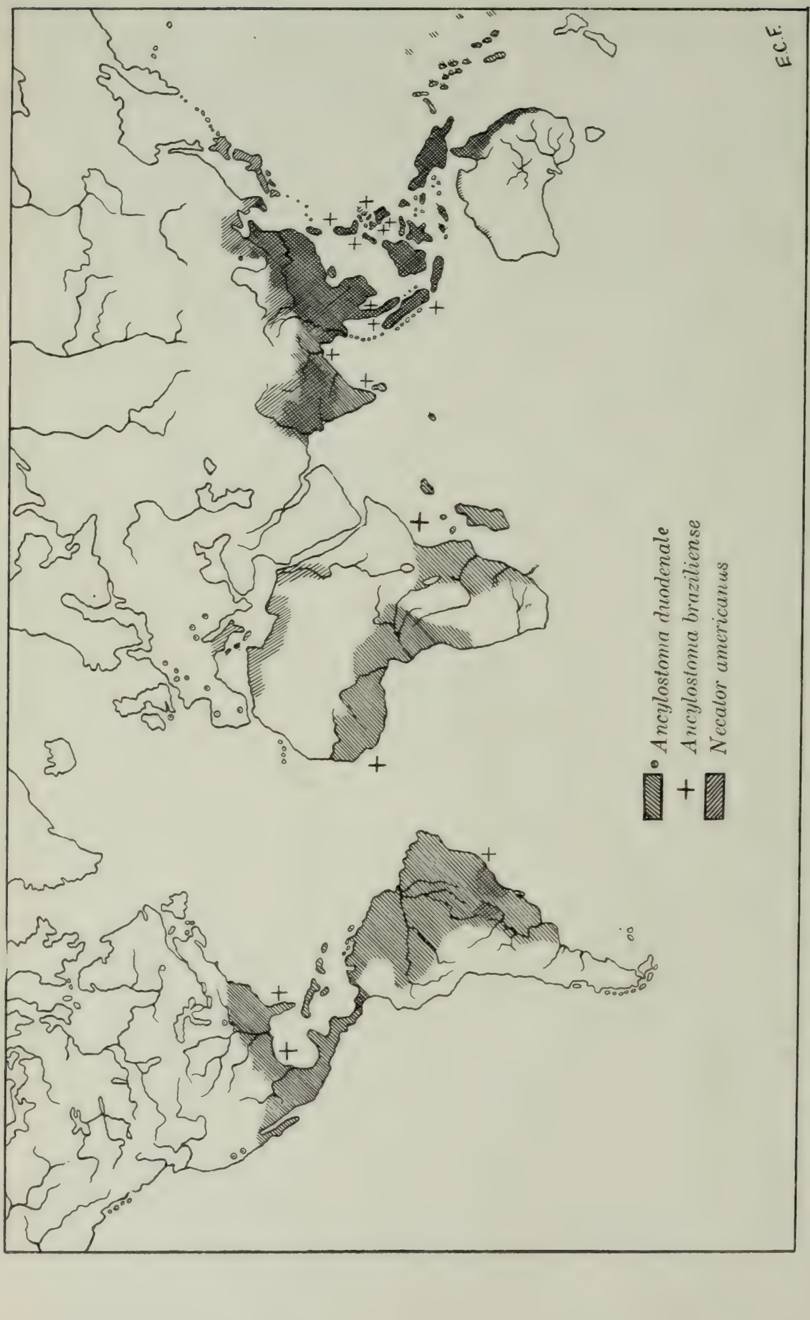

FIG. 206.—Map showing the distribution of the important species of human hookworms. (Original.)

The migration of peoples accounts for the following present distribution.

1. *The Americas.*—(*a*) The Southern United States.—*Necator americanus* introduced by the Kaffir and Mosambique slaves from Africa. (*b*) Central and South America as far south as the Argentine.—*Necator* has been introduced by the same source as (*a*) and also by Tamils, Bengalis and Javanese. In one province of Brazil where there was heavy colonization by Spaniards, Italians and Portuguese, the ancylostome-index rises to 11.2 per cent. In another province the relatively high ancylostome-count is due to Japanese colonists. *Ancylostoma braziliense* is present as an incidental infection in this area. (*c*) Little is known about the hookworm infections of the aboriginal Amerinds, either in North America or in the Andean areas, but the recent investigations of Soper (1926) among the native Paraguayans indicate a very high ancylostome-index, and suggest that these people may have come from northern Asiatic stock.

2. *Europe.*—The only species found in Europe, except in returned colonists from the Southern United States or Brazil is *Ancylostoma duodenale.* This species occurs in the agricultural regions of Italy, Sicily, Sardinia, Spain, Austria, Hungary, Jugo-Slavia and Bulgaria; in the Loire Basin in France; and in the mines of Cornwall, Liége, Mons, Charleroi, and in Germany, Poland and Silesia. It was the cause of the great epidemic during the construction of the St. Gothard tunnel. *Ancylostoma braziliense* is not known to be present in Europe.

3. *North Africa.*—There is an exclusively *Ancylostoma duodenale* infection in North Coastal Africa.

4. *Tropical and South Africa.*—As far as is known there is an exclusively *Necator americanus* infection in this region, except for an incidental infection with *A. braziliense.*

5. *The Malay Peninsula.*—From native kampongs or villages which are usually separate from the Tamil and Chinese villages the parasite has been found to be almost entirely *Necator* (only 0.25 per cent ancylostome-index). *A. braziliense* is not uncommon.

6. *Java.*—(*a*) West Java. This is practically the same as that in the Malay Peninsula, *i. e.,* less than 1 per cent ancylostome-index. *A. braziliense* has also been recorded from this part of the island. (*b*) Mid-Java. There is a fairly high ancylostome-index (up to 10 per cent) in Central Java, due to contact with the Chinese immigrants.

7. *Sumatra, Celibes and New Guinea.*—*Necator* is usually the predominant species, but the index depends on the contact with Chinese immigrants. *A. braziliense* is present in Sumatra.

8. *Southern India and Ceylon.*—This is predominantly a *Necator* infection, but the ancylostome-index may reach 65 per cent, depending on the number of returned Tamils who have been in contact

with Chinese carrying an infection of *Ancylostoma* originally acquired in China. *A. braziliense* is recorded from Ceylon.

9. *Northern India.*—Lane (1916) states that *Necator* is the only form found in the Darjeeling district but Sikhs who have been in contact with *Necator* carriers in the Malay States for ten years or more have an ancylostome-index of 51.2 per cent. Likewise indentured workers in Fiji, hailing from the Central United and Northwestern Provinces, after more than five years' residence were found to harbor 27.5 per cent *Ancylostoma*. *A. braziliense* occurs in Northeastern India.

10. *Siam.*—The only form found is said to be *Necator* (Kerr, 1916).

11. *French Indo-China.*—The only form found is *Necator* (Noel Bernard, 1922).

12. *China.*—(*a*) The Cantonese and Hainanese harbor *Necator* up to 90 per cent. The infection with *Necator* is progressively less up the coast to Shanghai, where possibly 50 per cent *Necator* occurs. In North China there are few indigenous infections with *Necator*. Cases in this area with a high *Necator*-index usually give a history of residence in South or Central China. (*b*) The hill tribes of Fukien have been found to harbor a pure *Ancylostoma* infection (Faust and Kellogg, 1929).

13. *Japan.*—The autochthonous infection consists of a pure culture of *Ancylostoma* but *Necator* has been introduced by returned emigrants and soldiers.

14. *The Philippines.*—Data show about 12 per cent *A. duodenale* infection (Leach *et al.*, 1923). The incidence of *A. braziliense* is appreciable.

15. *Polynesia.*—There is a pure *Necator* infection in Fiji, where ancylostome carriers have not colonized.

16. *Australia.*—The Queensland aborigines are pure *Necator* carriers. In West Australia the aborigines are all *Ancylostoma* carriers.

Sufficient data are at hand, therefore, to demonstrate that the type of hookworm present in a given population at the present day varies on the one hand according to the autochthonous index and on the other according to the past and present migration and intermingling of peoples. Chinese have modified the hookworm-index of the Malay, Dutch East Indes and parts of Polynesia and Micronesia, while the recent Japanese colonization of certain states in Brazil is responsible for the ancylostome infection there. Altogether, however, the most profound transfer of the hookworm has been that imported into the Americas with the African negro, and the imposition of this infection upon the American aborigines and European settlers. The supposed differences in pathogenicity between the two important human species of hookworms needs to be restudied on the basis of this information.

Epidemiological Study of Hookworm Disease.—While there is a tremendous literature on hookworm disease, by far the greatest part of it is general information. Much of it is admirable in helping an epidemiologist who plans to undertake a hookworm survey to get the "lay of the land" and to understand the psychology and customs of the people involved in the disease. But unfortunately too much stress has been laid on the "campaign," consisting primarily of "treatments" and too little has been done in learning about the underlying biological and epidemiological reasons for the existing conditions.

Although many careful workers in hookworm areas have recognized this discrepancy, Baermann (1917) working on the problem in the Netherlands Indes was the first person to devise a practical method of isolating the hookworm larvæ from the soil. It is not too much to say that, from the epidemiological standpoint, Baermann initiated the modern scientific study of the hookworm problem.

There are two prerequisites for undertaking field investigation on this problem: (1) accurate methods for determining the infective index in the infected population; and (2) similarly reliable procedures for determining the pollution in the soil. The former has become more and more refined until we now have concentration methods (see p. 527), which are accurate for all practical purposes. The latter need is met by the Baermann apparatus for the isolation of hookworm larvæ. (For use of this apparatus see p. 532.)

With these tools at hand and the technique of their use perfected, the first essential step in undertaking a field problem of this nature is the *selection of a typical area* in an infected district, on which and in in which the survey is to be made. Such a reconnaissance naturally divides itself into three main parts which, however, are closely bound up with one another: (1) a preliminary survey of a representative group of the population to determine the hookworm index; (2) an investigation of the prevalence and distribution of soil pollution in that area; and (3) a reconnaissance of the natural and artificial means whereby the vicious cycle of reinfection of the population is perpetuated. The problem as conceived by Cort may be outlined as follows:

I. Survey of a representative group of the population to determine the hookworm index.

Methods of selection of a representative group. Prejudice of ignorant and superstitious races to submit stools.

1. *Custom of stooling:* Place: Difference between men and women, women usually utilizing commodes in houses. Cleaning of these commodes as a possible source of infection. Type of stool: solid, mushy, liquid.
2. *Food:* Relation to balanced diet.
3. *Age, sex and occupation* of each person.

4. *Intelligence:* General average for the race, determined through a few leading questions from a person speaking the native language fluently, and acquainted with the psychology of the population.
5. *Clinical symptoms of the disease:* Hemoglobin-index, emaciation, splenic index in children; general toxemia.
6. *Other diseases to be ruled out:* malaria, amœbiasis, ascariasis, hymenolepiasis, fluke infections (in Africa and the Orient), kala azar, idiopathic splenomegalies.

The hookworm-index: Eggs per gram of feces.

1. *Stoll method vs. other concentration methods.* Estimate of worms present based on above methods. Incidence of severe infections (infestations) as compared to benign (non-clinical) cases. Underlying causes. Percentage of population infected. Relation to clinical symptoms.
2. *Sample treatments* to check records and estimates. Types of hookworm (*Necator* or *Ancylostoma*) present. Other helminths present. Relative reliability of egg-finding and diagnosis (laboratory and clinical) as checked by worms passed after administration of an anthelminthic.

II. Prevalence and distribution of soil pollution.

Customs of the population in stooling analyzed from this standpoint.

1. *Tropical countries in general:* factors of isolation, shade, humidity.
2. *Mohammedan and Hindu countries.* Religious tenets and prejudices.
3. *River populations* in the Orient.
4. *Children* and other promiscuous defecators.

Direct defecation onto the land compared with conservation of human feces for fertilization of land. Night-soil disposal as a factor in the spread of the infection. Direct pollution and reinfection; small areas involved as intensive potential spots of infection. Human manure; methods of ripening. Ripening jars and pits; collecting and distribution in barrows or buckets and in boats. Relation of drying of human night-soil to viability of ova. Crop-rotation and fertilization of fields as related to infective incidence of the farmer class.

Methods of determining infective incidence in soil. Baermann apparatus. Factors involved: hydrotropism, thermotropism, capillarity of soil. Consistency of the soil: clay, clayey-loam, sandy-loam, humus, loess. Temperature and moisture of the area in determining the growth of larvæ and their viability.

Prerequisite: ability to differentiate larvæ of the hookworm, *Strongyloides* and free-living nematodes found in the soil.

III. Natural and artificial means for reinfection of the population.

Conditions in homes for spread of disease. Relation of sex to infective incidence. Domestic animals as vectors of the infection.

Customs of the people as regards clothing, particularly of the feet and hands. Bare-feet in the tropics and rice-growing areas. Bare-hands in mines.

Type of crop raised: Relation to development of larvæ, and customs of people in defecating. Coffee, tea, rubber plantations; plantain and banana; date and cocoanut palm groves; cocoa bean; cotton and rice; mulberry groves; legumes and cereals other than rice.

Type of mine in which hookworms develop: placer *vs.* deep shaft. Coal, iron, lead, tin, diamond.

Social and religious customs favoring reinfection.

IV. Bearing of epidemiologic surveys in hookworm districts on other, possibly more malignant, infections.

Pathogenicity and Symptomatology of Hookworm Disease.—Hookworm infection, if sufficiently heavy, causes hookworm disease, no matter what the race or climate or who the individual is. There are, among other effects of hookworm infestation, (1) a definite physical retardation of the individual, (2) a mental retardation, and, associated with these two (3) an economic loss to the individual and to the community in hookworm infested areas.

Physical Discompensation.—This is due to loss of blood, both relative and absolute, and to toxic secretions of the worms, which affect the hematopoietic and endocrine organs and retard sexual maturity (Figs. 207 and 208).

Mental sluggishness among the backward whites, which was for many years believed to be due to hookworm disease, has received no better etiological proof than that produced by Kofoid and Tucker (1921) in their work with the army intelligence test staff, in which they found that there was a high correlation between low intelligence and hookworm infection among the soldiers hailing from the Southern United States. In these same studies it was shown that there was also a higher correlation between other diseases such as pneumonia, measles, etc., for those who harbored hookworms than among those free from hookworm infection. In other words, hookworm infection lowered bodily resistance.

Economic Loss.—Infected men in the tropics (Brazil) have been estimated by Darling and Smillie (1921) to be 25 per cent less efficient than non-infected ones. Treatment of infected laborers in Central and South America has increased efficiency as much as 33 per cent and the earning capacity from 14 to 39 per cent. These same differences have been found to obtain in India and Trinidad.

The Blood Picture in Hookworm Infection.—The anemia characteristic of this disease is usually directly correlated with the number of worms harbored. There is a general feeling that *Necator* causes less disturbance than *Ancylostoma,* as explained on the basis that *Necator* is not known to consume blood, and that gross evidences of hemorrhage are wanting. Darling has estimated that it takes an infection of 12 worms to depress the hemoglobin index of

Fig. 207

Fig. 208

Figs. 207 and 208.—Clinical cases of hookworm infection; Fig. 207, subject aged twenty-two years. (After Dock and Bass, Hookworm Disease, Courtesy of C. V. Mosby Company.)

Fig. 208.—Boy aged fourteen years. (After Dock and Bass, Hookworm Disease, Courtesy of C. V. Mosby Company.)

man 1 point (95 being considered normal). On this basis it would take 240 worms to depress the index to 75 and nearly 1000 to reduce it to 15. Yet there seem to be other important factors involved, for Leach has shown in the Philippines that the hemoglobin index may be very low in patients harboring only a very few worms. De Langen (1922) argues in favor of the toxic origin of the anemia, since he found little blood in the gut of worms (*Necators?*) expelled from

patients, no positive blood tests from the stools, and a lower amount of bilirubin (indicative of hemolysis) than in normal blood. He believes, therefore, that the cause is a toxic effect on the hematopoietic organs, causing an aplastic anemia, and in severe chronic cases an injury beyond recovery. In most cases the hemoglobin-index increases slowly upon removal of the worms by an anthelminthic but some cases stubbornly resist increase for some length of time following expulsion of the worms.

Darling (1920) has grouped hookworm cases into three types, according to their severity: (1) infections in which the blood loss is compensated; (2) moderately severe infection in which the compensation is disturbed; and (3) severe cases in which the compensation is broken.

1. *Blood Loss Compensated.*—These are light infections. Anemia is negligible and clinical symptoms are lacking. These individuals are essentially carriers, who are not as dangerous to the community as heavily infected individuals but who, on exposure to malaria, dysentery, etc., are more susceptible than non-infected individuals.

2. *Blood Losses Causing Discompensation.*—Individuals in this class manifest symptoms due to insupportable loss of blood. The time of appearance of the symptoms depends on the patient's ability to resist the effects of the infection, hence age and sex are important factors. Children are less resistant than grown men, and women are less resistant than grown men, although more resistant than children. Under-nourishment and famine are supplementary causes for the actual breakdown. The symptoms of this type consist in heartburn, flatulence, a feeling of fullness of the abdomen and epigastric pain, all of which are usually relieved by a full meal. Geophagia is not uncommon. Fever if present is intermittent. There is a more or less physical weakness or "laziness," which causes persons engaged in strenuous occupations to take up less heavy work and those in light occupations to be disinclined to work. Usually there are also vasomotor disturbances, with dyspnea and at times heart murmurs.

3. *Complete Blood Discompensation.*—Heavy infestations commonly result in nutritional and endocrine insufficiency. There is constipation or diarrhea, with poorly-digested food passed in the stool. The pallor of the skin is marked, with "yellows," so characteristic in light-skinned races. There is edema, particularly of the face and lower extremities and emaciation of other parts. "Pot-belly" is also a characteristic physical sign. Puberty is delayed. In long-standing cases there is a weak pulse, mental dullness, apathy and impotence. The condition becomes more and more exaggerated in such cases and terminates in complete physical exhaustion, cardiac failure and anasarca, unless relief is effected by expulsion of the worms.

At the time of infection the lesions produced in the skin, as the filariform larvæ effect an entry into the body, give rise to *hookworm dermatitis,* or "ground-itch." Ashford (1911) describes this dermatitis (Fig. 209) as "first an itching; then edema and erythema; then a papular eruption ending in vesicles." Within thirty to sixty days after a massive invasion of the filariform larvæ has been effected through the skin the characteristic symptoms, both objective and subjective, make their appearance. The subsequent course of the infection depends on the severity of the disease.

Diagnosis.—This is based on finding the characteristic hookworm ova in the feces. While there is theoretically a measurable difference between the size and shape of *Ancylostoma* and *Necator* eggs, in practical diagnosis they are difficult to differentiate. *Strongyloides* eggs which are similar in appearance but slightly smaller (50 to 58 by 30 to 34 μ), are evacuated only after a severe purge. The eggs of the several species of *Trichostrongylus* are larger (73 to 80 by 40 to 46 μ) and have more elliptical ends.

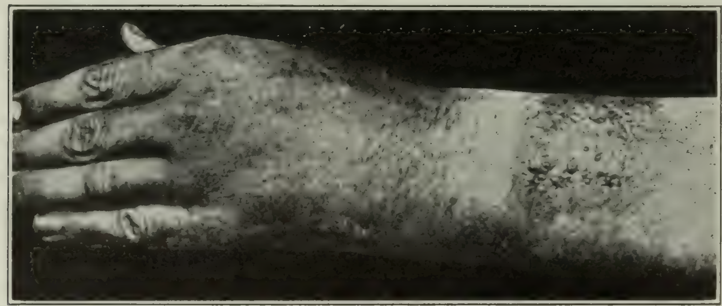

Fig. 209.—Experimental hookworm infection, showing swelling of wrist and tendons of hand and vesicle formation. Second day. (After Claude A. Smith in Dock and Bass, Hookworm Diseases, Courtesy of C. V. Mosby Company.)

Therapeusis.—The ultimate aim in hookworm therapy is to secure a dependable anthelminthic, cheap, readily obtainable and easily administered, which will effect a maximum amount of cures with a minimum toxic effect on the patient. To this end various drugs have been tried out, including eucalyptus oil, chloroform, beta naphthol, santonin, thymol and oil of chenopodium, but up to 1921 no drugs had been found even moderately satisfactory except thymol and oil of chenopodium. The most satisfactory study of their potency was that undertaken by Darling and his colleagues (1920) in the Malay States, Java and the Fiji Islands. In this area they had an opportunity to study the use of the drugs on Malays, Indians, Chinese and native Fijians.

Their preliminary investigations with thymol and oil of chenopodium (thymol, 60 grains, oil of chenopodium, 3 cc.) were very

promising, so that they made a thorough analysis of the effect and potency of these and other drugs. Their basis of determination as to the vermicidal action of the medicant was the number of worms removed compared with the total number of worms harbored.

The drug to be tested and the dosage used was first administered as a *trial treatment*. The worms obtained in this manner were carefully collected from the stool, counted and records made. A week or more following this a treatment of oil of chenopodium was administered (1 cc. in freshly-filled capsules, for three successive hours). This constituted a *test treatment*. The stools were carefully examined, the worms collected and records made. If ova were still present in the stool following this examination, an *extra treatment* of 3 cc. oil of chenopodium was administered. In each case adequate preparation of the patients was made by reducing the diet the day before and giving a magnesium sulphate purge. The morning of the treatment milk was substituted for the breakfast and an hour following the drug a second $MgSO_4$ purge was given. They were not allowed to work that day. Stools were examined on that and the following two days. Other tests to determine the value of fasting and of the purgatives were made; also the optimum dosage. In these tests both oil of chenopodium and thymol were found to be satisfactory (96.16 and 88.6 per cent efficiency respectively) in removing all the worms on the first dosage. With a diminution of the dosage in these two drugs, the efficiency was lessened. It was found that ancylostomes were more resistant to treatment than necators, and in this respect oil of chenopodium was more effective. In practically all cases where a patient's choice was inquired for, oil of chenopodium was preferred.

With both drugs certain concomitant and after-effects of the drug of practically the same type were occasionally noticed, consisting of dizziness, muscle incoördination, headache, burning of the stomach, vomiting, etc., and with oil of chenopodium, occasionally a semi-comatose condition, with deafness as an after-effect. Where $MgSO_4$ and castor oil were administered as purges on comparative groups, the former was found to be more satisfactory, since less of the drug was absorbed.

Carbon Tetrachloride Therapy.—Carbon tetrachloride has been known to have anesthetic powers for three-quarters of a century, but its use as a vermicide was not demonstrated until Hall made a study of its effect on the strongyles of domestic animals. The results he obtained were so successful that in 1921 he called the attention of the medical profession to the possibility of its use in human hookworm therapy. Following this Leach (1922) in Ceylon and Lambert (1924) in Fiji made careful preliminary investigations on its potency and its effect on patients. Leach used up to 12 cc. of the drug with no untoward effects and, in cases of prisoners to be hanged,

which were treated and later came to autopsy, no hookworms were found, although *Enterobius* and *Trichocephalus* still remained attached to the mid-intestine. In Lambert's preliminary tests 96 to 98 per cent efficiency was obtained by the administration of 3 cc. of CCl_4. He secured 85 per cent cures from the first dosage. Following these tests Lambert treated more than 20,000 cases, and with the single-treatment method reduced the infestation from nearly 100 per cent to 9 per cent without the loss of a single case. The cost of the treatment was less than 9 cents gold per patient. The dosage given was 0.2 cc. to the year of age up to fifteen years, when the adult dosage of 3 to 4 cc. was administered. The drug was placed on a tablespoon, floated on water and swallowed. After preliminary administrations it was found that routine $MgSO_4$ purgative three hours after the drug removed practically all of the after-effects. Leach had similar success in his 25,000 cases treated in the Philippines.

Smillie and Pessoa (1923), working in Brazil, treated preliminary cases with CCl_4 and reported that the results obtained in their experiments were "nothing short of marvellous." However, certain of their cases had toxic after-effects believed by them to be due to the drug (*i. e.*, fatty degeneration of the liver), but these cases were chronic alcoholics. This has led them to try out smaller dosages (1 to 1.5 cc.) which they have found unsatisfactory. They conclude that 3 cc. is the maximum safe dose for an adult. They recommend the use of the drug as follows: (1) light supper; (2) no breakfast; (3) 7 A.M. CCl_4 (c. p.) given in doses of 2 minims per year of age up to the maximum amount, administered either in hard gelatin capsules or floated in a tablespoonful of water; (4) 9 A.M. Purge of $MgSO_4$; and (5) 12 noon. Light meal.

Contraindications.—(1) Alcoholism; (2) pulmonary or heart complications; and (3) pyrexia. Lampson and Minot (1928) have also shown that calcium deficiency produces toxemia following CCl_4 administration.

The treatment should not be repeated within a lesser interval than three weeks. No more than two treatments should be given.

More recently tests on a large scale have shown that a combination of CCl_4 and oil of chenopodium is more efficient than either drug administered by itself. This is due to the fact that oil of chenopodium, while less potent for hookworms than CCl_4, narcotizes any ascarids which may be present, thus preventing unnecessary gastro-intestinal disturbances or unnecessary absorption of the drug into the intestinal wall due to activity of the ascarids following carbon tetrachloride treatment alone. The most favorable combination of these anthelminthics, together with pre-treatment preparation and post-treatment care, is as follows: (1) light supper; (2) no breakfast; (3) 2.2 cc. CCl_4 (c. p.) and 0.8 cc. oil chenopodium, floated on a

tablespoon; (4) two to three hours later, $MgSO_4$ or Na_2SO_4 purge; and (5) noon meal.

Prophylaxis.—Prevention of hookworm disease may be divided into two categories, namely, (1) prophylaxis in those climates and countries where human dejecta are not used for fertilizing agricultural and garden plots, and (2) prophylaxis in countries where it is customary to use human excreta for fertilizer. The former type of country may be further divided into (*a*) warm temperate climates populated by a civilization possessing high intelligence capable of comprehending the significance of the elementary laws of personal and community hygiene; and having a central governmental agency with power to make and enforce sanitary laws; and (*b*) tropical climates populated with peoples of a more mediocre intelligence, where dependence must be placed on plantation and estate owners, village chiefs etc., for coöperation, or where appeal must be made to the "psychology of the crowd."

Since hookworm disease involves only one host, man. and since there is no multiplicative period outside of man (as in malaria, fluke infections and strongyloidiasis) it may be reduced or eliminated from any community by (1) the individual avoiding contact with the soil the year round; (2) the sanitary disposition of night-soil; and (3) treatment of infected individuals. The first and the third methods tend to reduce the infection in man, while the second and third reduce the source of infection. In the long run both amount to practically the same thing.

In the United States and similar areas of infection in Europe the program for prevention may be stated as follows: (1) Every person should wear shoes the year round, and miners in infected areas should wear leather gloves and other body-covering. (2) Every person should use either toilets connected with sewers or sanitary latrines. Sewers are in use in the large cities of the Southern United States and are known to constitute a very important agency in reducing all forms of intestinal diseases. They can be extended into the smaller cities and towns and particularly into the negro districts of such municipalities with extraordinary benefit to the community. Sanitary cesspits can be utilized in the homes of persons of moderate means, but there is still left a moiety of the population unsupplied with such improved sanitary conveniences. Furthermore, it is just this part of the population that is most seriously affected. Sanitary latrines have been talked about and devised ever since the hookworm problem has been appreciated by our sanitarians, but in practice they have usually been a failure, either through faults in the type of construction or through the expense of such a building. For the rural community a closed-back latrine, with a deep pit and house set upon the pit is desirable, so as to prevent animals from grubbing into the hole. In places where poor,

insanitary and uncomfortable outhouses are provided, the individual frequently chooses a place to stool in a corn field or other secluded spot, and while this may meet the temporary need, it is known to be the most intense bed for hookworm larvæ to breed. The problem can be most successfully dealt with by the passage of sanitary regulations compelling proper latrines to be built and giving administrative officers power to enforce such regulations.

In many countries where field investigators have worked there are many factors involving climate, race and custom, that enter into the problem and its solution. The habits of certain types of these groups have been summed up by Darling (1922) and Faust (1924). The greatest success has been attained in undertaking preventive measures in these countries by enlisting the interest of plantation owners (tea, coffee, rubber, etc.) in the enterprise and in proving to them that the worm is of positive economic value to them. This work has been carried on along the following lines:

1. Constructing of sanitary or semi-sanitary outhouses near "coolie-lines."
2. Treatment of infected individuals.
3. Educational propaganda.

In China, Japan, parts of India and parts of Egypt (as well as in Southern France) where human manure is needed as fertilizer in the intensive scheme of agriculture, an additional factor is involved, namely, the danger from conservation of the feces and spreading of it on the soil. Oldt (1926) has shown that the addition to night-soil of commercial ammonium sulphate of a 12 per cent strength will furnish a fertilizer sterilized against hookworm embryos within one day of mixing. The solving of this problem is the more important in view of the fact that the day is not far off when Western nations as well as Orientals will have to return all fertilizer, including human dejecta, to the soil.

Methods for Determining the Percentage of Infection in a Given Area.—These are two-fold, involving (1) the infection in the human population, and (2) the infection in the soil. The former is determined fairly accurately by using either (*a*) the brine floatation of eggs passed in the feces of a representative group of the area (see p. 528) or (*b*) the Stoll egg-count from a similar fecal sampling (see p. 530). The latter is determined by using the Baermann apparatus for isolation of the infective larvæ from the soil (see p. 532).

The most practical proposal in hookworm-disease prophylaxis has been advanced by Darling (1922) from his extensive study of the problem in the Orient and in Brazil. It consists of *mass treatment* of heavily infected populations. With the improved methods of egg diagnosis and the experience gained in field studies it is now possible to map out an area for treatment without elaborate preparation or great expense. Such a program is based on the fact that

even though there is a tendency for the number of worms harbored by an individual to diminish with time (at the approximate rate of 12 per cent or more per annum), the worm-index is kept up by new infections. On the average a community receives an infection from the soil commensurate with the amount it puts into the soil, no more and no less. "A great deal of what has been called racial immunity to hookworm infection will undoubtedly prove to be due to racial differences of personal hygiene." Treatment of groups of individuals heavily parasitized by hookworm eliminates 95 per cent of the worms and cures about 85 per cent of the group (Fig. 210). If the entire group is treated soil pollution immediately drops and

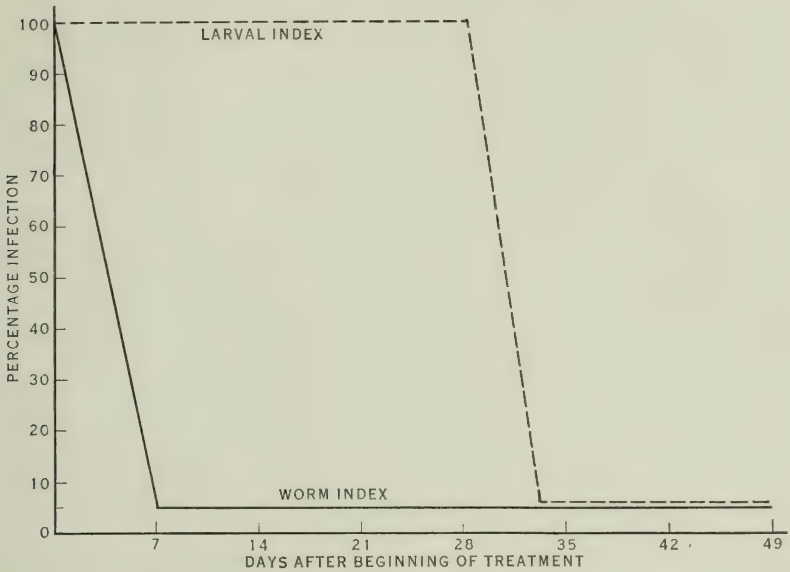

Fig. 210.—Graph representing the reduction in percentage of hookworms in the human population and larvæ in the soil following mass therapy. (After Darling.)

reinfection is minimized. Thus the group loses all but a negligible infection, which corresponds to an index clinically unimportant. Under these conditions one initial treatment and one after the larval index had dropped should practically free the population of hookworm disease, unless infection is contracted or introduced from outside sources.

Darling's Definition of Mass Treatment.—"By mass treatment is meant the administration of vermicide to large or small bodies of people—all the inhabitants of a community, village, district or neighborhood; all the inmates of a plantation, institution or any other group of persons living on and polluting and infesting more or

less the soil of one area." Where an average of 150 or more worms per individual are present in the mass of an untreated population, the work should be prosecuted. Other features recommending mass treatment are: (1) the difficulty of identifying and locating individuals; (2) the reduction of soil pollution resulting from the treatment; (3) the psychology of the "follow the crowd" instinct; and (4) the bringing of larger groups under treatment.

"CREEPING ERUPTION" IN THE SOUTHERN UNITED STATES.

Various clinicians in the Southern United States, particularly in Florida and Texas, have observed cases of so-called "creeping eruption," believed to have been due to fly larvæ. Extensive observations and investigations by Kirby-Smith (1917–1927), and by Kirby-Smith, Dove and White (1926, 1927) in the vicinity of Jacksonville, Florida, where the disease is a serious and extensive clinical entity, have resulted in the discovery that the etiological agent is the filariform larva of *Ancylostoma braziliense.* The infection is usually contracted after contact of exposed parts of the body with moist sand or earth, not necessarily near human habitations, but accessible to dogs which are known to harbor the infection in that area. It is most prevalent during the moist months of the year. At the point of invasion of the skin a reddish, itchy papule develops. Within two or three days the "eruption" consists of a linear, tortuous or serpiginous subepithelial tunnel, produced by the larvæ migrating within the skin. It is accompanied by intense itching, which frequently provokes scratching on the part of the patient and leads to secondary infection. It first develops as a narrow erythematous lesion along the path traversed by the worm. Soon a slightly elevated line can be palpated; this line becomes vesicular and the surface of the abandoned portion of the channel becomes dry and crusty. The larva migrates from a fraction of an inch to several inches each day. Such lesions may be present on every part of the body, although invasion of the larvæ most commonly occurs on the hands and feet. The tunnel is within the *stratum Malpighii* and usually has the corium as a floor and the *stratum granulosum* as a roof. Local eosinophilia and round-cell infiltration may be present in the immediate vicinity of the lesion. The migration of the larva may continue for several days or even weeks. Its final fate has not been demonstrated.

The lesion produces an itchy sensation, which is almost intolerable to some patients, causing insomnia, loss of appetite and, in certain extreme cases, loss of weight and vitality. Successful treatment has been effected by the local application of ethyl acetate in collodion, local freezing with ethyl chloride spray or carbon dioxide snow, and by radiotherapy. Dakin's solution is indicated where secondary

infection has developed. Prophylaxis consists in protection of the skin from moist sand or earth in endemic foci and in treatment of the reservoir hosts (dogs and cats) for hookworm infection.

Superfamily Trichostrongyloidea Cram, 1927.

This superfamily is composed of strongylate nematodes in which the buccal capsule is lacking or only rudimentary. They are long attenuate worms with a conspicuous bursa copulatrix. All of the human parasites in this group belong to the type family **Trichostrongylidæ** Leiper, 1912, the species of which are characterized by the absence of a buccal capsule and dental apparatus and by the presence of a large bursa with well-developed rays. These species are commonly parasitic in the digestive tract of ruminants and, except for *Trichostrongylus orientalis,* are less commonly parasites of man than of herbivorous mammals. All of the members of this family with known life histories require only one host, but have a free developmental larval period.

Genus Trichostrongylus Looss, 1905.
(genus from θρίξ, thread and στρογγύλος, round).

17. **Trichostrongylus colubriformis** (Giles, 1892) Ransom, 1911.

Synonyms.—*Strongylus colubriformis* Giles, 1892; *Strongylus instabilis* Railliet, 1893; *Strongylus subtilis* Looss, 1895; *Strongylus retortæformis* Zeder, 1800 *pro parte? Trichostrongylus subtilis* Looss, 1905; *Trichostrongylus instabilis* (Railliet, 1893) Looss, 1905.

Trichostrongylus colubriformis is a small, slender worm, with a reddish or creamy color when alive. It has been recorded from the duodenum and fourth stomach of several ruminants, including the domestic sheep, Dorcas gazelle, the Arabian and the Bactrian camel, the goat, the prong-horned antelope, the roe deer and the bharal. It has also been found in the small intestine of the Arabian baboon and has been obtained as a human infection in Egypt (Looss) and in India (Lane, Chandler), as well as in Armenia (Kalantarjan, Skrjabin Memorial Volume). The male worm has a length measurement of 4 to 5.5 mm. and a greatest diameter of 80 μ in the prebursal region. The head measures only about 10 μ in cross-section. The bursa is bilobed (Fig. 211*A*) with the externo-lateral ray usually broader than the other rays and the postero-lateral small and closer to the externo-dorsal than the latter is to the dorsal. The dorsal ray is bifid, each branch having a double point. The spicules (Fig. 211*B*, *C*) measure 135 to 145 μ long, while the gubernaculum (Fig. 211*C*, left) is slender, of a bright yellowish-brown color, and has a length of 70 μ. The terminal portion of the spicules is fairly sharp, with a definite but not high elevation. The female worm measures 5 to 6 mm. in length by 80 μ in diameter at the level of the

vulva, with a gradual tapering toward the anus (Fig. 211 *D*). The distance between the anus and the caudal extremity ranges from 55 to 70 μ. The vulva is longitudinally elongated, measuring 50 to 55 μ. The eggs are oval-elliptical, transparent, and measure 73 to 80 μ in length by 40 to 43 μ in lesser diameter. They develop and hatch outside of the body of the host, the rhabditiform larvæ metamorphosing into the infective filariform type in about six days at 22 to 25° C. They may enter the body either *via* the skin or the mouth, and follow the same course of intra-mammalian development as the hookworm.

Pathogenicity and Symptomatology.—In case large numbers of these worms develop in the human intestine, they produce a severe secondary anemia.

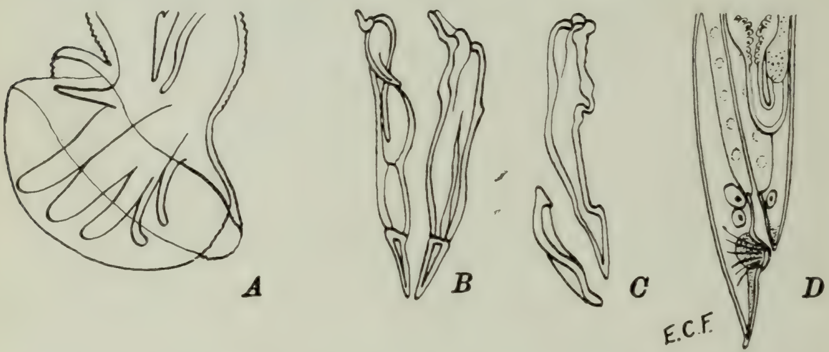

Fig. 211.—*Trichostrongylus colubriformis.* *A*, bursa of male worm, × 250; *B*, *C*, copulatory spicules, ventral and profile views, × 250; *D*, posterior end of female worm, × 150. (After Looss, in Centralblatt f. Bakteriologie u. Parasitenkunde.)

Diagnosis.—Upon finding the characteristic ellipsoidal eggs in the feces of a suspected patient. These eggs are much longer and have more pointed ends than hookworm eggs, but the ova of the several species of *Trichostrongylus* are difficult to differentiate from one another.

Therapeusis.—Similar to that for hookworm infection.

Prognosis.—Since the reservoir infection is in ruminants, it seems probable that man incurs the infection from raw consumption of plant stems and leaves contaminated with the dung of parasitized reservoir hosts, in a medium sufficiently moist to allow development of the free-living larval stages.

18. **Trichostrongylus probolurus** (Railliet, 1896), Looss, 1905.

Synonym.—*Strongylus probolurus* Railliet, 1896.

This species has been found as a natural infection in the duodenum of the domestic sheep, the Dorcas gazelle, the Arabian camel, the

Bactrian camel and man. The human cases have been reported from the Egyptian fellaheen by Looss (1905), and more recently from Armenia by Kalantarjan, (1927). In color, shape and size the adult worms are practically the same as those of *T. colubriformis*. The latero-ventral ray of the bursa copulatrix is the broadest of the rays (Fig. 212*A*), while the externo-lateral is next in size. The postero-lateral ray curves so far dorsad that its terminus may be dorsal to that of the externo-dorsal ray. The spicules (Fig. 212 *B, C*), are slightly shorter than those of *T. colubriformis* and relatively thick, with a well-defined terminus having a conspicuous elevation, and a sharp angle facing the gubernaculum. They have a twisted appearance under low magnification. The gubernaculum is slightly longer than that of *T. colubriformis* and somewhat darker in color. The posterior portion of the body of the female (Fig.

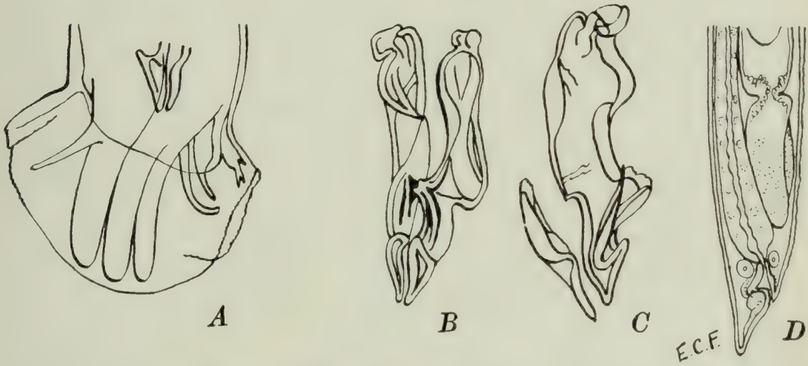

FIG. 212.—*Trichostrongylus probolurus.* *A*, bursa of male worm, × 250; *B*, *C*, copulatory spicules, ventral and profile views, × 250; *D*, posterior end of female worm, × 150. (After Looss, in Centralblatt f. Bakteriologie u. Parasitenkunde.)

212 *D*) is slightly plumper than that of *T. colubriformis*, with a short blunt caudal extremity (40 to 50 μ distance between anus and tip of tail). The vulva has a conspicuous internal thickening, and is elongated longitudinally, measuring about 76 μ long. The transparent ellipsoidal eggs measure 76 to 80 μ in length by 43 to 46 μ in lesser diameter.

The life cycle of the worm, symptomatology of the infection and prophylactic aspects are similar to those of *T. colubriformis*.

19. **Trichostrongylus vitrinus** Looss, 1905.

This species has been found as a natural infection in sheep, goats, camels and man in Egypt (Looss, 1905) and in ruminants in North America (Ransom, 1911). Both the male and female worms of this species average about 0.5 mm. longer than those of *T. colubriformis* and *T. probolurus*. The bursa of the male is noticeably larger than

that of the other species reported from man (Fig. 213*A*). The rays are relatively more slender and straighter, the ventral and the postero-lateral being conspicuously straight digitate processes. The spicules (Fig. 213*B*, *C*) are long (160 to 170 μ); the acuminate points lack the hook-like projection of many species of the genus. The slender gubernaculum measures 85 to 95 μ in length. The female (Fig. 213 *D*) is subcylindrical from the level of the loop of the posterior ovary to the anus, while the post-anal portion becomes reduced to a sharp point, with a somewhat ventral curve. The vulva is short and oblique in position, with slight elevation above the surface. The eggs are transparent elliptical objects, measuring 84 to 90 μ in length by 46 to 50 μ in lesser diameter.

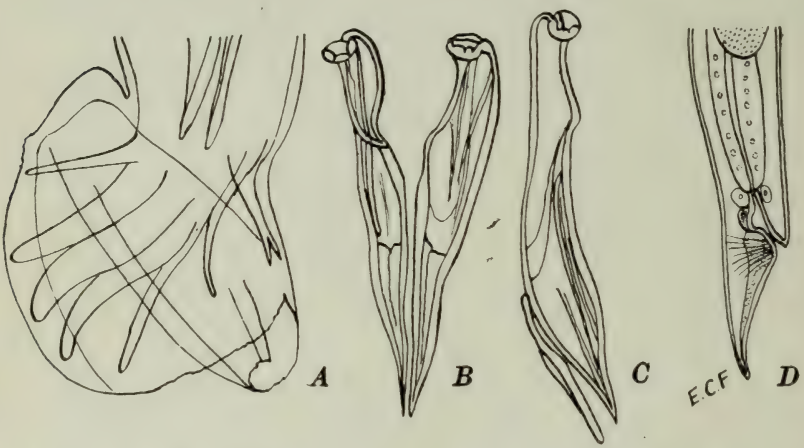

FIG. 213.—*Trichostrongylus vitrinus.* *A*, bursa of male worm, × 250; *B*, *C*, copulatory spicules, ventral and profile views, × 250; *D*, posterior end of female worm, × 150. (After Looss, in Centralblatt f. Bakteriologie u. Parasitenkunde.)

The life cycle of the worm, symptomatology of the infection and prophylactic aspects are similar to those of *T. colubriformis*.

20. **Trichostrongylus orientalis** Jimbo, 1914.

Synonym.—*Strongylus subtilis* Looss, 1895 *pro parte*.

This species of *Trichostrongylus* is not uncommon among the agricultural populations of Japan, Korea, Formosa and Central and South China. Kalantarjan (1927) has also found this infection in Armenians. It is the only species of the genus originally discovered as a human infection. The author has also found this species in fat-trailed sheep and Bactrian camels in North China. The trichostrongylid originally reported by Ogata, by Ijima, and by Kitamura and Oishi from human cases in Japan and Korea under the name *Strongylus subtilis* Looss, 1895, is undoubtedly referable

to *T. orientalis*. Jimbo records the infection from 219 individuals and from 27 autopsies. In most cases only a few worms were present, exceptionally 50 or more. The common seat of infection was found to be the duodenum, but occasionally worms had wandered

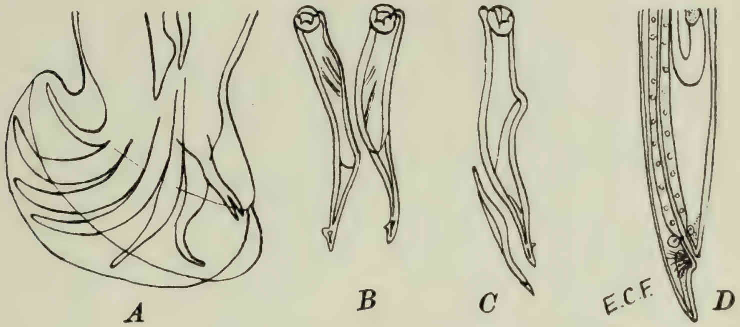

FIG. 214.—*Trichostrongylus orientalis*. *A*, bursa of male worm, × 250; *B*, *C*, copulatory spicules, ventral and profile views, × 250; *D*, posterior end of female worm, × 150. (Original.)

into the adjacent portion of the stomach or the jejunum. The adult worms are grayish-white in color, the males measuring 3.8 to 4.8 mm. and the females 4.9 to 6.7 mm. long. The heads of the males average 7 μ in diameter, and of the females, 9 μ, while the

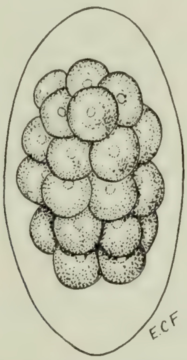

FIG. 215.—Egg of *Trichostrongylus orientalis*. × 500. (Original.)

greatest diameter of the former is 72 to 79 μ, and of the latter, 75 to 83 μ.

The bursa (Fig. 214*A*) is bipartite. The three lateral rays are close to one another, the latero-ventral being the broadest. All three are bowed ventrad, as is also the more slender postero-lateral. The externo-dorsal is somewhat S-shaped. The dorsal ray is bifur-

cated at its extremity. The two spicules (Fig. 214*B*, *C*) measure 119 to 133 μ long, and are brownish-yellow in color. There is a distinct minute hook at the end of each spicule. The gubernaculum measures 65 to 85 μ in length; in front view it resembles a pen nib, but in profile view it is spindle-shaped, with a slight bowing. The posterior end of the female (Fig. 214 *D*) is conical, with a graceful inward curving toward the caudal extremity. The distance from the anus to the tip of the tail is 65 to 86 μ, with a slight ventral curve. The eggs (Fig. 215) measure 75 to 91 μ in length by 39 to 47 μ in lesser diameter.

The life cycle of this worm is similar to that of *T. colubriformis*. The clinical symptoms in mild infections are *nil*. Carbon tetrachloride, as administered in hookworm infection, is a specific therapeutic. Man appears to be the common natural host of this species, while other mammals are only incidentally infected.

Genus Hæmonchus Cobb, 1898.
(genus from αἷμα, blood and ὄγχος, spear).

21. **Hæmonchus contortus** (Rudolphi, 1803) Cobb, 1898.

Synonyms.—*Strongylus contortus* Rudolphi, 1803; *Strongylus filicollis* Rud. of Molin, 1861; *Strongylus placei* Place, 1893.

This nematode is one of the commonest parasites of domestic sheep throughout the world. It has also been recorded from the goat, the addax, the moose, the prong-horned antelope, the chamois, the American bison, the deer, the roe deer, the mule deer, the bharal, the argali, the Mexican mountain sheep, the Newfoundland caribou, and domestic cattle. De Magalhaes has recovered this species once from man in Brazil. On the basis of eggs found in the feces W. S. Sweet (1924) reported the presence of this parasite in three aborigines in Northern Australia. The worms live attached to the wall of the fourth stomach of the ruminant host, and occasionally to the duodenal mucosa. The buccal cavity in members of this genus is provided with a single pharyngeal lancet (Fig. 216*A*) which may project slightly through the oral aperture. There are well-developed cervical papillæ (Fig. 216*B*) about 0.3 from the anterior end of the body. The head has a diameter of about 30 μ. The males are 10 to 20 mm. long with a maximum thickness of 0.4 mm. and the females, 18 to 30 mm. long by 0.5 mm. in cross-section. Anteriorly the body is gradually attenuated. There is an asymmetrically situated dorsal lobe (Fig. 231*C*) of the bursa copulatrix attached to the left lateral lobe on its inner side near its base. The three lateral rays originate from a common stem, as do the ventro-ventral and the latero-ventral rays. The externo-dorsal is a long digitate process, that of the left side having its origin close to the base of the common stem of the dorsal ray. The spicules measure 0.3 to 0.5

mm. in length and become gradually attenuated from their point of insertion to their distal tips. The tips are provided with minute knobs and a subterminal barb, the barb of the right spicule being slightly larger. The gubernaculum is 200 μ long, flat, fusiform, and has rounded thickened edges. In the female worms the vulva

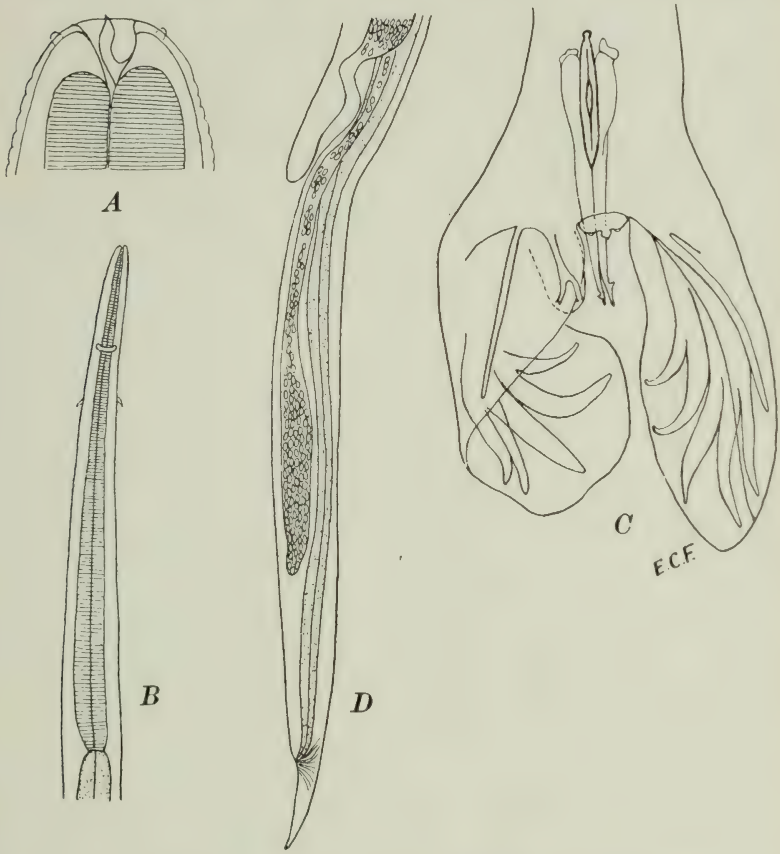

FIG. 216.—*Hæmonchus contortus.* *A*, head showing pharyngeal lancet, × 600; *B*, anterior portion of worm showing cervical papillæ and esophagus, × 46; *C*, bursa of male worm, with copulatory spicules and gubernaculum, × 75; *D*, posterior end of female worm, showing vulva and anus, × 24. (After Yorke and Maplestone, Nematode Parasites of Vertebrates; *C*, somewhat modified.)

(Fig. 216 *D*) is situated 3 to 4.5 mm. from the caudal extremity. It is protected by a posteriorly projecting linguiform process about 0.5 mm. long. The anus is 0.4 to 0.63 mm. from the tip of the tail. The postanal region is sharply pointed. The eggs are transparent oval objects measuring 75 to 95 μ long by 40 to 50 μ in lesser diameter and contain incompletely developed larvæ when laid.

Ransom (1906) has shown that *Hæmonchus contortus* undergoes direct development outside the body of the mammalian host. Hatching takes place from a few hours to several days after the eggs are passed in the feces. The rhabditiform larva is provided with a masticatory cardiac bulb for the ingestion of the fecal matter on which it feeds. After several days or weeks the larva becomes metamorphosed into an ensheathed filariform type, which is resistant to freezing and desiccation. Under stimulation of moisture this filariform larva crawls up stems and blades of grass, gradually reaching a level where it is ingested by grazing animals. When swallowed it continues to develop and becomes fully adult in the course of two or three weeks.

Pathogenicity and Symptomatology.—This nematode attacks the mucous lining of the digestive tract of its hosts, letting blood by means of its pharyngeal lancet. Heavy infestation leads to anemia, edema, emaciation and profound digestive disturbances. The infection causes considerable mortality in young animals. In man the infection gives rise to a secondary anemia likely to be confused with hookworm anemia. Brumpt and Joyeux have shown that the aqueous extract of the worms is hemolytic.

Diagnosis.—Since the eggs are readily confused with those of other strongylate nematodes it is necessary to obtain specimens of adult worms for specific diagnosis.

Therapeusis.—Thymol causes the evacuation of large numbers of the worms.

Prophylaxis.—Rotation of crops, so as to obtain uninfested fields for grazing animals, is an effective method of controlling the infection in reservoir hosts. Human beings should refrain from eating uncooked grass or other vegetation in endemic areas, and should thoroughly cleanse the hands after working in infested fields.

Genus Mecistocirrus Railliet and Henry, 1912.
(genus from μήχιστος very long, and *cirrus*, thread).

22. **Mecistocirrus digitatus** (v. Linstow, 1906) Neveu-Lemaire, 1914.

Synonyms.—*Strongylus digitatus* v. Linstow, 1906; *Strongylus fordii* Daniels, 1908; *Strongylus gibsoni* Stephens, 1909; *Nematodirus digitatus* (v. Linstow, 1906) Railliet and Henry, 1909; *Mecistocirrus fordi* (Daniels, 1908) Neveu-Lemaire, 1914; *Mecistocirrus tagumai* Morishita, 1922, Nematode sp. nov. Sheather, 1918.

This nematode is a fairly common parasite of the pig, the sheep, cattle and water buffaloes in India, the Malay Archipelago, China and Japan. The worms live in the stomach and adjacent portion of the small intestine of these animals. This species has been recorded once from the feces of man in Hongkong but there is considerable

probability that the material in question was not human in origin. The worms are ivory-colored. The males measure 16 to 21 mm. in length by 0.45 mm. in transverse diameter and the females, 19 to 43 mm. in length by 0.5 mm. in diameter. The anterior end is rounded, with six inconspicuous papillæ (Fig. 217*A*). There is a

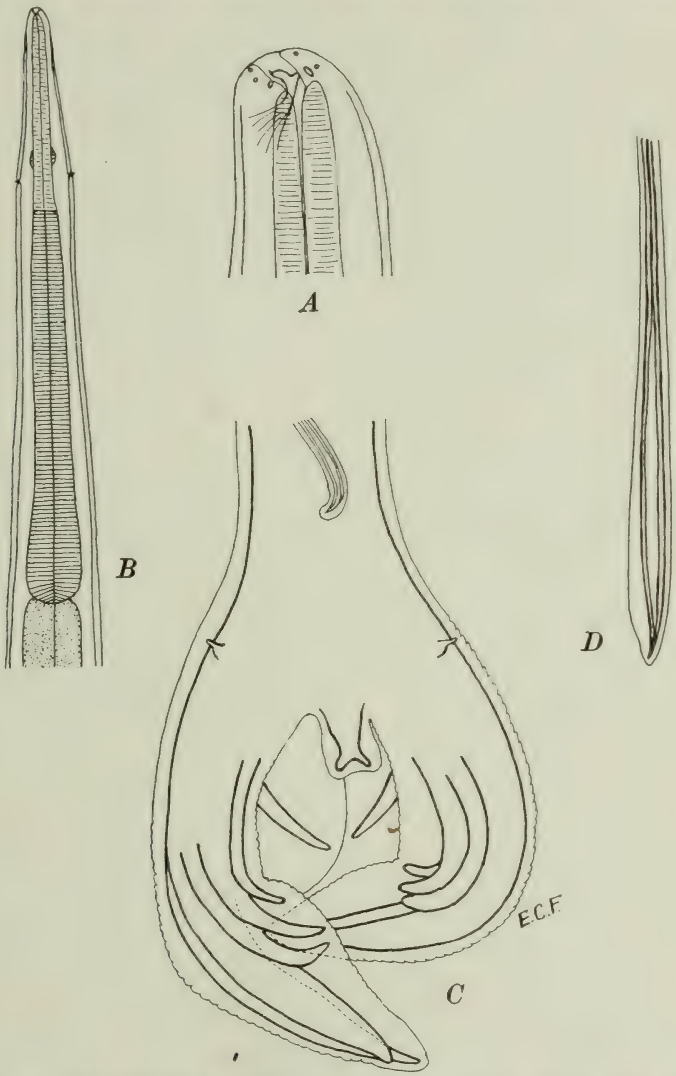

FIG. 217.—*Mecistocirrus digitatus.* *A*, oral end, showing papillæ and paryngeal lancet, × 330; *B*, anterior portion of body, showing esophagus and cervical papillæ × 46; *C*, bursa of male worm, with prebursal papillæ and extremity of copulatory spicule, × 46; *D*, detail of distal portion of copulatory spicule, × 215. (After Yorke and Maplestone, Nematode Parasites of Vertebrates, slightly modified.)

single large pharyngeal lancet present. The cervical papillæ lie in small depressions in the cuticle at the level of the junction of the anterior and second quarters of the long slender esophagus (Fig. 217*B*). In the male there is a pair of prebursal papillæ. The bursa is completely divided into three lobes (Fig. 217*C*), a small dorsal and two spatulate laterals. The latero-ventral and externo-lateral rays are equally large and conspicuous. The ventro-ventral and the externo-dorsal rays are very slender, and the median- and postero-laterals are intermediate in size. The spicules are long and lanceolate (Fig. 217 *D*). The gubernaculum appears to be lacking. The vulva of the female worm is a prominent transverse slit about 0.3 mm. in front of the anus. The latter is situated 0.2 mm. from the caudal extremity. The tip of the tail is bluntly pointed. The eggs are large transparent oval bodies, measuring 95 to 110 μ in length by 50 to 55 μ in lesser diameter. They are laid in the morula stage. The life cycle of the worm is not known but is believed to be similar to that of the other trichostrongyloid species. The clinical and prophylactic aspects of infection with this species have not been studied.

Superfamily Metastrongyloidea Cram, 1927.

The members of this superfamily are characterized by the absence or rudimentary condition of the buccal capsule, while the males have a small bursa with stunted rays, of which the externo-lateral is usually wider and frequently several times the size of the other rays. All species of this group belong to the type family **Metastrongylidæ** Leiper, 1908, which has the characters of the superfamily. The worms live in the respiratory or circulatory system or in the cranial sinuses of mammals. The one species of this superfamily recorded from man, *Metastrongylus apri,* is a parasite of the lungs.

Genus Metastrongylus Molin, 1861.

(genus from *μετά*, behind and *στρογγύλος*, round).

23. **Metastrongylus apri** (Gmelin, 1790) Railliet and Henry, 1907.

Synonyms.—*Gordius pulmonalis apri* Ebel, 1778; *Ascaris apri* Gmelin, 1790; *Fusaria apri* Zeder, 1803; *Strongylus suis* Rudolphi, 1809 *pro parte; Strongylus paradoxus* Mehlis, 1831 *pro parte; Strongylus elongatus* Dujardin, 1845; *Strongylus longevaginatus* Diesing, 1851; *Strongylus apri* (Gmelin, 1790) Blanchard, 1895.

This nematode is filiform in shape and creamy or brownish in color, and has a mouth bounded by a pair of lateral trilobed lips of which the median lobes are the largest. The buccal cavity is practically lacking. The esophagus is elongate and slightly club-shaped posteriorly. The males measure 12 to 25 mm. in length by 160 to 225 μ in greatest diameter, and the females, 20 to 50 mm. in

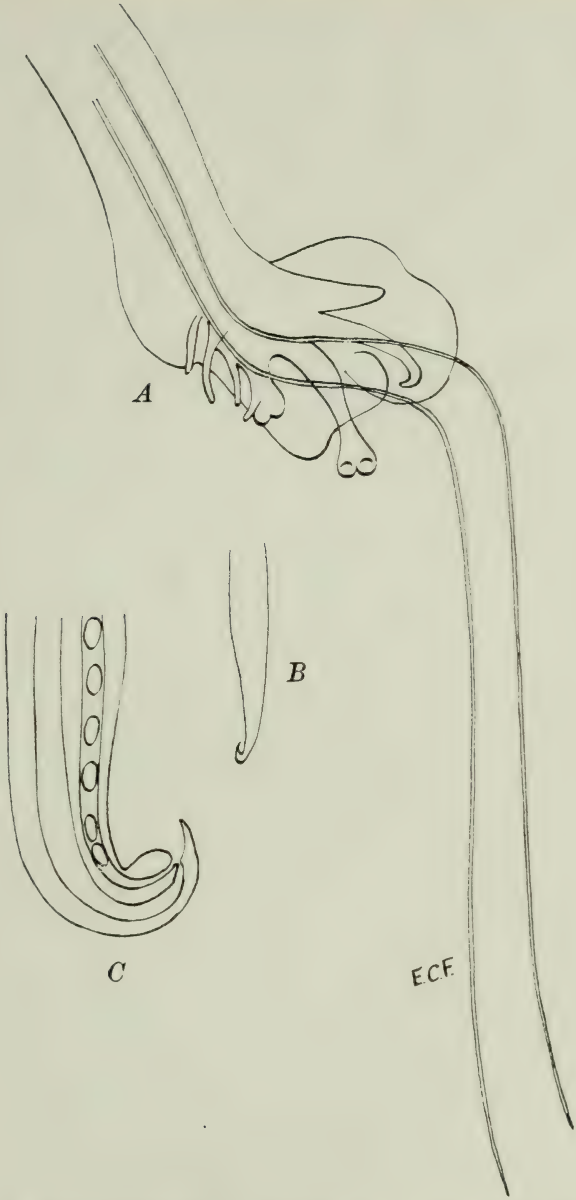

FIG. 218.—*Metastrongylus apri.* *A*, posterior end of male worm, showing bursa with rays and filiform copulatory spicules, × 75; *B*, hooked end of spicule, greatly enlarged; *C*, posterior end of female worm, showing openings of vulva and anus, × 75. (Original.)

length by 400 to 450 μ in greatest diameter. The worm is a common parasite of the lungs of pigs and wild boars, being present in the bronchioles and bronchi and at times in the trachea. Sheep and oxen have also been reported as hosts. It has been found three times in man, twice in the human respiratory tract [once by Diesing (1845) in a boy, aged six years, once by Rainey (1855) in an adult], and once in the digestive tract of a pork vender (Chatin, 1888). The bursa copulatrix of the male (Fig. 218*A*) is bilobed, with an additional median dorsal lobe, each of the lateral lobes being supported by five rays, of which the ventro-ventral and latero-ventrals are processes distinctly separated from one another, the externo-lateral is large and long and is clearly separated from the other laterals, the medio-lateral is broad and rounded, and the postero-lateral is represented by a small digitate process, the externo-dorsal is small and thin and the dorsal is a small bifurcated process. The spicules are long hair-like structures (4 mm.) with a delicately hooked distal end (Fig. 218*B*). The entire posterior end of the female is strongly recurved. The vulva is situated immediately in front of the anus (Fig 218*C*). The eggs are ellipsoidal and vary in size from 57 to 100 μ by 39 to 72 μ At the time of oviposition they contain well-developed larvæ. The hatched rhabditiform embryos have a length of 220 to 350 μ and a diameter of 10 to 12 μ. Although the life cycle is unknown it is believed to be direct, without an intermediate host.

Pathogenicity and Symptomatology.—The lungs of infected pigs show whitish patches around the infected areas. In young pigs these worms frequently give rise to a fulminating bronchitis, which proves fatal.

Diagnosis.—On recovery of the characteristic eggs from the exudate of the respiratory tract or after having been swallowed and passed in the feces.

Therapeusis.—Unstudied.

Prophylaxis.—One of the human cases was a vender of pork. Infection in man undoubtedly occurs from contamination with the exudate of infected pigs or from slaughtering of infected animals.

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CHAPTER XXVI.

THE MYOSYRINGATE NEMATODES (CONTINUED).

OXYURATA AND ASCARIDATA.

Suborder Oxyurata Cram, 1927.

(ENTEROBIUS AND RELATED FORMS).

THE members of this suborder are relatively small monoxenous species, of which the males have a reduced bursa or caudal alæ, supported by rays or papillæ, and one (exceptionally two) imperfectly chitinized copulatory spicules. The body of the females is drawn out into a point posteriorly. The eggs, which are oviposited in the embryonated state, are flattened on the ventral side. All of the known species are grouped under the type superfamily **Oxyuroidea** Railliet, 1916, which has the characteristics of the suborder. Six families of **Oxyuroidea** have been found in vertebrate hosts. The two oxyuroid species reported from man, *Enterobius vermicularis* and *Syphacia obvelata,* belong to the type family **Oxyuridæ**.

Family OXYURIDÆ Cobbold, 1864.

The species of this family have a posterior cardiac bulbus clearly separated from the anterior cylindrical part of the esophagus. The male worm lacks preanal suckers or other specialized muscles. The female is usually much longer than the male, and possesses a double germarium and connecting tubular oviducts and uteri, emptying into the vulva, which latter organ is usually preëquatorial in position, but may be situated even as far posteriad as the preanal region. The eggs are ellipsoidal, fairly large and asymmetrical. No intermediate host is required for species of this family.

GENUS ENTEROBIUS LEACH, 1853.
(genus from *εντερον,* intestine and *βίος,* life).

24. **Enterobius vermicularis** (Linnæus, 1758) Leach, 1853.

Synonyms.—*Ascaris vermicularis* Linnæus, 1758; *Fusaria vermicularis* (Linnæus, 1758) Zeder, 1803; *Oxyuris vermicularis* (Linnæus, 1758) Lamarck, 1816; *Oxyuris vermicularis* (Linnæus, 1758) Bremser, 1819; *Oyxurias vermicularis* (Linnæus, 1758) Stiles, 1905; *Fusarella vermicularis* (Linnæus, 1758) Seurat, 1916.

The pinworm or seatworm of man has been known since ancient times. It is cosmopolitan in its distribution, its incidence of infection in a given population depending not so much on the climate or public sanitation as on the personal habits of the individuals in that population. Man is the only known natural host of this species.

Structure of the Adult Worms and Life Cycle.—The adult worms live in the cecum, appendix vermiformis, and adjacent parts of the colon and small intestine, the worms being attached by their heads to the mucosal layer of the intestinal wall. The oral end is provided with three labia which are capable of being retracted into the body. There is no definite buccal cavity. Lateral alæ extend along the cephalic margins. The male worm (Fig. 219 *A*) has a length of 2 to 5 mm. and a transverse diameter of 0.1 to 0.2 mm. The posterior end is strongly curved ventrad. There is a single conspicuous spicule measuring 70 μ in length, with a sharply-curved terminus (Fig. 220 *B*, *C*). A gubernaculum is lacking. The caudal alæ are supported anteriorly by a pair of pedunculated papillæ and posteriorly by a pair of large papillæ; in addition, there are two pairs of more median postanal sessile papillæ. The female (Fig. 219 *B*) has a length measurement of 8 to 13 mm. and a transverse diameter of 0.3 to 0.5 mm. The attenuate tail constitutes nearly one-third of the worm. The anus is approximately at the junction of the middle and posterior thirds of the body and the vulva opens just in front of the junction of the anterior and middle thirds. The vagina proceeds some distance posteriad from the vulva before forking to form the anterior and posterior arms of the uterus. The two oviducts and corresponding ovaries are capillary tubules coiled back and forth several times in the middle half of the body. As the two branches of the uterus become more and more crowded with eggs the organ becomes increasingly distended, so that

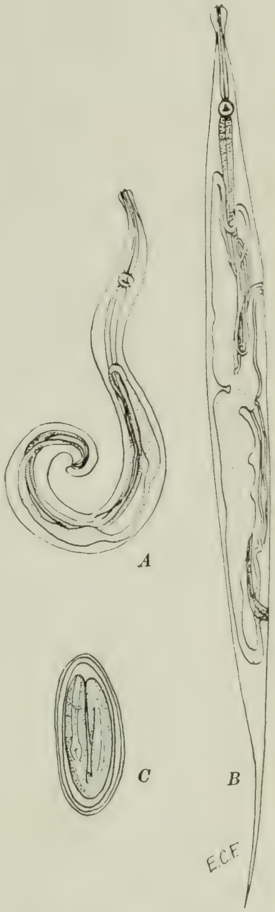

FIG. 219.—*Enterobius vermicularis.* *A*, male worm, showing digestive and reproductive systems. × 16. (After Leuckart, Parasiten des Menschen.) *B*, female worm, showing digestive and reproductive systems. × 16. (After Leuckart, Parasiten des Menschen.) *C*, egg, with rhabditiform larva. × 280. (Original.)

in gravid individuals the entire body is filled with eggs. According to Koch (1925) the pressure of the gravid uteri on the esophagus releases the hold which the females have on the intestinal mucosa and sets the worms free. Thus they migrate from their former position, usually passing out of the large bowel, crawling actively into the

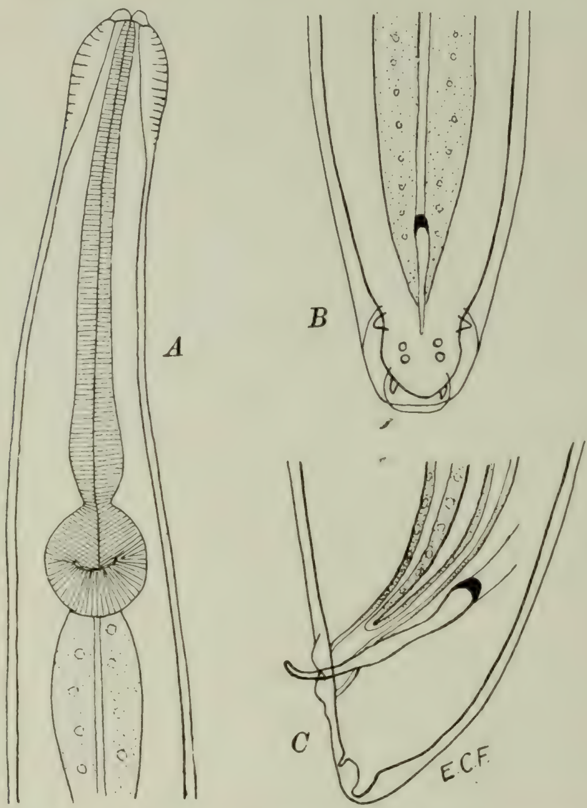

FIG. 220.—Details of *Enterobius vermicularis*. *A*, anterior extremity of worm, ventral view. × 75. *B*, posterior extremity of male, ventral view. × 215. *C*, posterior end of male, lateral view, showing cloaca and adjacent regions of rectum and ductus ejaculatorius, with spicule. × 450. (Adapted from Yorke and Maplestone.)

perianal hairs, and frequently in female hosts reaching and entering the vagina. The eggs are not commonly laid within the bowel. In the perianal region the worms soon become dried and as a result explode, throwing out showers of fully embryonated eggs. These eggs are all equally mature when they are dispersed (Fig. 219 *C*). In profile view they are flattened on the ventral surface and rounded

on the dorsal aspect. The transparent shell consists of two layers, an outer albuminous one, which tends to cause the eggs to agglomerate, and an inner embryonic membrane. Preliminary to hatching the two membranes become separated except at one point on the dorsal surface just behind the cephalic pole.

Enterobius vermicularis requires neither an intermediate host nor a period of incubation outside of the body. The intense itching, produced by the gravid females crawling around in the perianal region and by the escape of the eggs, which are scattered like a shower of lycopodium powder upon the rupture of the body of the mother worm, usually results in scratching of the affected part by the patient. This allows the eggs to get in under the finger nails, so that sooner or later some of them are taken into the mouth. Or, due to their ability to resist desiccation they may remain attached to soiled clothing for sometime, and in this way may be ingested by another individual and result in his infection.

On reaching the duodenum the egg hatches and the rhabditiform larva is set free. This larva measures 140 to 150 μ in length by 10 μ in transverse diameter. It is only slightly active and is provided with no cephalic armature. The development of the larva of *Enterobius vermicularis* is able to take place without migration through the body of the host. After two moults in the small intestine, the adolescent worms mate and proceed to the large intestine, there to become attached to the mucosal layer and develop to adulthood. When the females become fully gravid they release their hold on the intestinal wall and on reaching the anus, pass out as previously described, the rupture of their bodies resulting in the dispersal of their eggs. The complete life cycle, as first worked out by Leuckart (1865), Grassi (1879) and Calandruccio (1888) and later by numerous other investigators, requires about two months' time.

Pathogenicity and Symptomatology.—Within the intestine the worms may occasion minute local areas of inflammation around the heads attached to the mucosal layer of the wall. The gravid females frequently wander into the lumen of the appendix and at times provoke a catarrhal inflammation which may involve the muscular layers or allow entrance of pathogenic bacteria. Necrosis of the mucosal layer of the cecum may expose the sympathetic nerve endings and give rise to serious reflex symptoms. Migration out of the rectum frequently causes congestion of the anal region, with pin-point hemorrhages and erosion of the mucous membrane and, at times, cutaneous eczema. Around the anus as well as within it there may be developed an unbearable pruritus which is temporarily relieved by scratching. Subcutaneous tumors of the anal region may also be produced. Irritation of the perineum may give rise to sexual disorders in both male and female subjects. Occa-

sionally the adult worms may wander into the small intestine; they have even been recorded from the stomach, esophagus and nares. In the event of their migrating into the region of the anterior ileum, the eggs reacting to the intestinal juices, hatch and auto-infection takes place without the eggs leaving the body of the host. In infants and to a certain extent in adults nervous symptoms of various types due either to direct irritation or to specific toxins absorbed by the body, have been commonly observed.

Diagnosis.—The eggs of *Enterobius vermicularis* are seldom found in the feces. In patients with a history of pruritus ani wipings or scrapings of the region affected may result in the recovery of eggs and portions of dead female worms. Since the female worms usually migrate out of the anus during the early hours of sleep, the perianal region of children suspected to having pinworms should be examined at such time for these worms. High soap-saline enemata may also cause the delivery of gravid females. In the absence of other infections which might produce it, eosinophilia of a mild degree may be suggestive of enterobiiasis.

Therapeusis.—Santonin, oil of chenopodium, thymol, β-naphthol and *filix-mas*, as administered for other helminthiasis, at times cause the elimination of some of the worms (usually only gravid females). High soap-saline or yatren enemata are also frequently effective in evacuating these females. Young females and males attached to the mucosa of the large intestine are seldom obtained by any of these treatments. Pruritus ani due to pinworms should be treated by the application of mercurial or other enterobicidal ointments. Invasion of worms into the appendix may produce appendicitis and require surgical intervention.

Prognosis.—Good, unless the infection gives rise to severe neuroses or secondary invaders gain entrance to the general circulation through lesions produced by the worms.

Prophylaxis.—Sanitary measures should be directed toward two ends, namely, prevention of reinfection of an individual already harboring the worms, and infection of contacts. Pinworms are more common in children than in adults; they are also more common in women than in men. This is due to contact between mothers or elder sisters and young children. Familial infections are usual, one member of the family conveying the viable eggs to another. Infected individuals should be provided with protective sleeping garments so that their hands do not become contaminated during sleep. Finally, since auto-infection may occur intra-intestinally, every effort should be made at regular intervals to remove all of the gravid females in order to prevent the infection from being self-propagating.

Genus Syphacia Seurat, 1916.
(genus from σίφω a tube).

25. **Syphacia obvelata** (Rudolphi, 1802) Seurat, 1916.

Synonyms.—*Ascaris obvelata* Rudolphi, 1802; *Fusaria obvelata* (Rud., 1802) Zeder, 1803; *Oxyuris stroma* v. Linstow, 1884; *Oxyuris obvelata* (Rud., 1802) Hall, 1916.

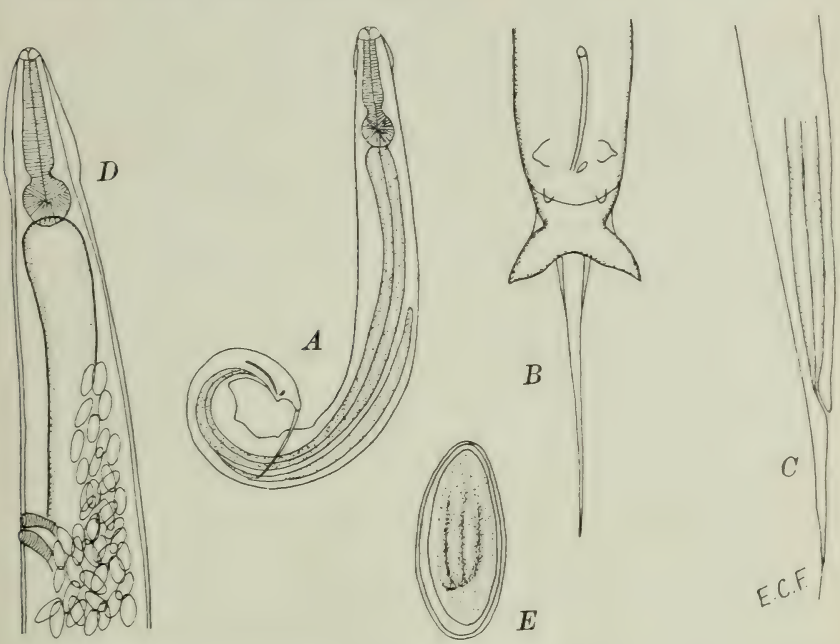

Fig. 221.—*Syphacia obvelata.* *A*, lateral view of male worm. × 75. *B*, caudal extremity of male, ventral view. × 330. *C*, posterior end of female worm, lateral view. × 215. *D*, anterior end of female worm, showing vulvar opening and uterus. × 330. *E*, egg, with developing embryo. × 150. (After Yorke and Maplestone.)

This species of oxyurid nematode is characterized by having three broad lips placed in a triradiate position around the mouth, by the absence of a buccal vestibule, and by having an esophagus consisting of an anterior club-shaped portion and a posterior cardiac bulbus separated from the former by a definite constriction. The cervical region is provided with a pair of relatively inconspicuous alæ. Both sexes have a long attenuated caudal extremity. The male (Fig. 221 *A*) measures from 1 to 1.6 mm. in length by 0.1 mm. in cross-section. Its posterior end is curved nearly 360 degrees ventrad. There are two or three cuticular mammillations on the ventral surface. The pericloacal region is provided with a pair of pointed alæ. There are two pairs of preanal papillæ and, in addi-

tion, one pair of conspicuous pedunculated postanal processes which support the caudal alæ (Fig. 221 *B*). The single spicule is long and slightly curved. The short gubernaculum is directed obliquely toward the spicule. Behind the caudal alæ is a stiff attenuated caudal extremity measuring 0.12 mm. in length. The female measures 3.5 to 5.7 mm. in length by 0.3 to 0.5 mm. in cross-section. The anal opening is about 0.12 mm. from the caudal tip (Fig. 221 *C*). The vulva (Fig. 221 *D*) is in the anterior part of the body, about 2.0 mm. from the cephalic end. It communicates by a short vagina, which frequently protrudes, with a very muscular ovejector, which leads into a single very long uterus. This latter, in turn, is succeeded distally by a pair of narrow receptacula seminis, lying side by side. Still further distad are the two delicate oviducts and ovarian tubules. The worms are oviparous. The eggs (Fig. 221 *E*) resemble those of *Enterobius vermicularis* but are very much larger (125 by 40 μ) and are somewhat more fusiform. They contain rhabditiform larvæ at the time of oviposition.

The life cycle of this species is probably direct without the intervention of an intermediate host. The infection is cosmopolitan as an intestinal parasite of rats and mice. One human case has been reported by Riley (1919) from an American child in the Philippines. Human infection is undoubtedly incidental and probably results from contamination with droppings from infected Muridæ.

Suborder Ascaridata Railliet and Henry, 1915.

(Ascaris and Related Forms).

The members of this suborder are polymyerian species in which there are usually three or six lips, although in some subgroups labia are lacking. In case there are three lips, one is median and dorsal and the other two are submedian and approximately ventral. There is no buccal capsule. The males either have two copulatory spicules or a single spicule. The females commonly have two ovaries but in species found in snakes there are more than two. The females are oviparous, the eggs being frequently unsegmented when oviposited. The development is usually direct, without an intermediate host, but a migration of the larvæ through the lungs of the host is not infrequently required before the worms may develop to adulthood. At present all of the families of this suborder are placed in the superfamily **Ascaroidea** Railliet and Henry, 1915, which has the characters of the suborder. All of the human representatives of the superfamily belong to the type family **Ascaridæ**.

Family ASCARIDÆ Baird, 1853.

The mouth of members of this family is either provided with three prominent lips supplied with papillæ or with three primary

lips and three secondary intermediate lips. The esophagus lacks a cardiac bulb. The males usually have two spicules. The tail of the female terminates conically and fairly abruptly. The vulva in most species is preëquatorial in position. In the species reported from man the males lack a precloacal sucker.

Genus Ascaris Linnæus, 1758.
(genus from ἀσχαρίς, helminth).

26. **Ascaris lumbricoides Linnæus,** 1758.

Synonyms.—*Stomachida vermis* Pereboom, 1780; *Stomachida pereboomii* Goeze 1782; *Ascaris suum* Goeze 1782; *Fusaria lumbricoides* (Linn., 1758) Zeder, 1800; *Lombricoides vulgaris* Merat, 1821; *Ascaris suilla* Dujardin, 1845; (?) *Ascaris maritima* Leuckart, 1876; (?) *Ascaris texana* Smith and Goeth, 1904.

Structure of the Adult Worms.—*Ascaris lumbricoides*, as an intestinal parasite of man and the pig, was well known to the physicians and naturalists of ancient times. Without question this species is the most cosmopolitan and most common animal parasite of man. This species has also been recorded from the gorilla. The worms are elongated cylindrical nematodes, tapering anteriorly and posteriorly to bluntly conical ends. The lateral lines appear as a pair of distinct whitish streaks along either side of the entire body length. The head is provided with a median dorsal broadly elliptical lip and a symmetrical pair of submedian ventral oval lips, all of which are finely denticulate. Each lip has on each of its lateral margins a pair of minute papillæ (Fig. 222 *B*). There is a small buccal vestibule in the median axis beneath the lips and behind this a cylindrical mucular esophagus, 10 to 15 mm. long. This leads directly into the mid-intestine, which continues to the subcaudal extremity of the body, where it empties into a short rectum which opens directly through the anal pore in the female and into the cloaca in the male. The male worm has a length of 15 to 31 cm. and a transverse diameter of 2 to 4 mm. Its posterior end is curved ventrad. The male genitalia form a long tortuously coiled tubule situated in the posterior half of the body, consisting of testis, collecting tubule and ductus ejaculatorius, the latter opening into the cloaca. Dorsal to the posterior terminus of the ductus is the pocket into which the 2 equal unwinged club-shaped spicules of 2 mm. length are retracted (Fig. 222 *C*). There is no gubernaculum. There are numerous preanal and postanal papillæ, situated symmetrically in four parallel lines preanally and in four groups of two and four single units postanally (Fig. 222 *C*). In the recurved posterior portion of the male traces of caudal alæ are sometimes seen. The female usually measures 20 to 35 cm. in length by 3 to 6 mm. in transverse diameter. Occasionally specimens develop to a length

of 40 to 49 cm. The vulva is situated near the junction of the anterior and middle thirds of the body. It leads into a conical vagina, which branches to form the paired genital tubules, each member containing uterus, receptaculum seminis, oviduct and ovary. These two members more or less parallel one another in a tortuous course throughout the posterior two-thirds of the body cavity. The uterine

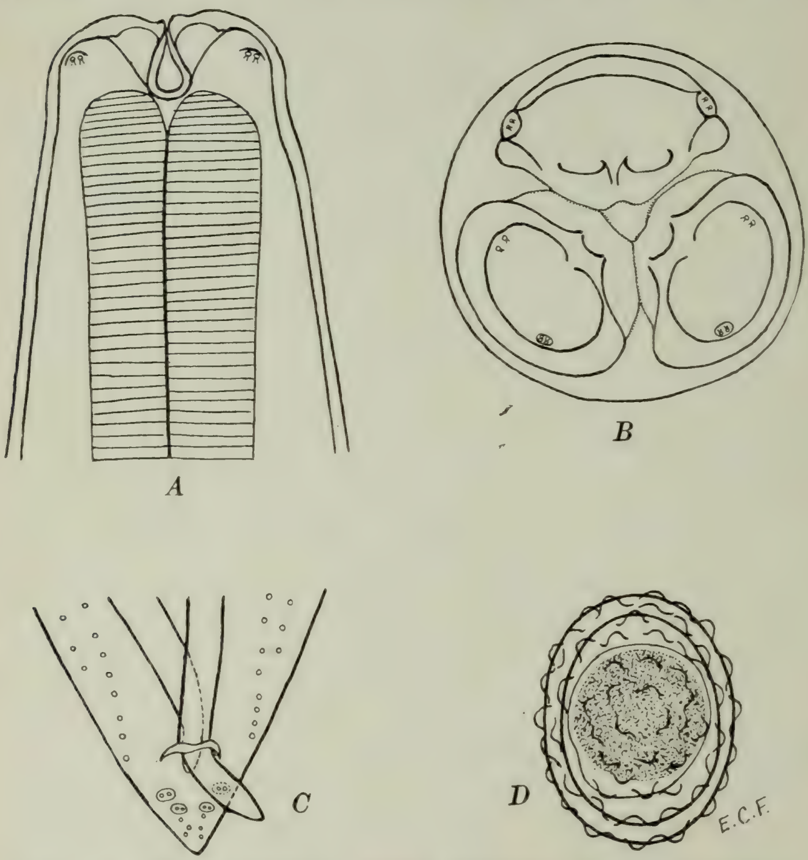

FIG. 222.—Detailed features of *Ascaris lumbricoides*. *A*, anterior extremity, ventral view. × 46. *B*, oral labia, head-on view. × 56. *C*, posterior extremity of male worm, ventral view. × 45. *D*, fertilized egg. × 500. (After Yorke and Maplestone.)

tubules are relatively broad and when stretched out may have a length of 200 mm. each. The ovarian tubules with their ducts may each have a length of 1250 mm. The total capacity of the genital tubules at any one time has been estimated at about 27 millions of eggs (Cram, 1925), and the average daily output of eggs for each female, 200,000 (Brown and Cort, 1927).

The fertilized eggs (Fig. 222 *D*) are oval in shape, with a thick transparent shell and an outer coarsely mammillated albuminous covering which is at times lacking. They measure 45 to 75 μ in length by 35 to 50 μ in lesser diameter. Eggs *in utero* are hyaline, but the albuminous layer becomes yellowish-brown from the bile pigment in the feces. At the time of oviposition the egg is usually unsegmented, the cytoplasm being densely impregnated with coarse lecithin granules. Unfertilized eggs are much longer, narrower, more elliptical in shape, and usually have a thinner shell and an irregular coating of albumin. The inner structure is unorganized and frequently contains large numbers of highly refractive granules. These eggs are most frequently passed by female worms when males are not present in the intestine of the host.

Development of the Eggs and Larvæ.—The development of *Ascaris lumbricoides* eggs is directly influenced by temperature, moisture and oxygen supply. In night-soil mixtures or in a cold dry climate they remain practically dormant. Yet freezing and desiccation not only do not ordinarily kill the eggs, due to the extremely good insulation afforded by the albuminous coat, but, on the other hand, frequently stimulate development. Temporary baths in strong chemicals are not injurious to the embryo and moderately strong solutions of formaldehyde accelerate development of the embryo *in ovo*. At 33° C. (which is the optimum temperature for growth) the embryo develops into a coiled rhabditiform larva ready to hatch in nine to thirteen days. Eggs in contaminated soil may apparently remain viable for five or six years. In moist heat of 80° C. or over the embryos are rapidly killed.

The embryonated eggs usually cause infection of the host by introduction *per os*. Occasionally, however, eggs containing fully developed larvæ ready to hatch may come in contact with open lesions of the skin, hatch in such pockets, and migrate to the lungs; rarely the eggs may hatch in moist alkaline soil and gain active entry through the skin. Upon being swallowed, fully-developed eggs usually pass through the stomach without hatching. Upon arrival in the duodenum the medium of the intestinal juices stimulates activity of the enclosed larvæ, which emerge two or more hours later through a V-shaped slit in the shell. Previous to hatching the larvæ becomes ensheathed. This sheath may be moulted just before hatching, at the time of hatching, or shortly afterward. The larvæ which emerge from the shell are elongate cylindrical objects, tapering at both ends, and measuring 0.2 to 0.3 mm. in length by 13 to 15 μ in transverse diameter. They are typical rhabditiform larvæ (Fig. 223), with a cylindrical esophagus measuring 78 to 90 μ in length and enlarged posteriorly into a cardiac chamber; and with an elongate intestine and a short rectal-cloacal portion.

Route of Migration Through the Body of the Host.—Stewart (1916) first showed that an extra-intestinal migration of *Ascaris* larvæ is normally required before they can proceed to complete development in the intestine. Ransom and Foster (1917) and Ransom and Cram (1921) demonstrated that the larvæ penetrate through the intestinal wall into the lymphatics and mesenteric veins, are carried to the right heart, either by way of the thoracic duct or the inferior vena cava, and thence to the lungs. Here they are filtered out of the blood stream, migrate into the alveoli and, after a period of growth, migrate to the small intestine by way of the bronchi, trachea, epiglottis, esophagus and stomach. During this period some larvæ occasionally migrate into aberrant foci, such as the peripheral lymph nodes, the thyroid, thymus and spleen, and even the brain and spinal cord, and in so doing may give rise to unusual symptoms. The period of migration is one of growth for the larvæ; they commonly increase in length during this passage from 0.2 or 0.3 mm. to 1.6 or 2.1 mm.

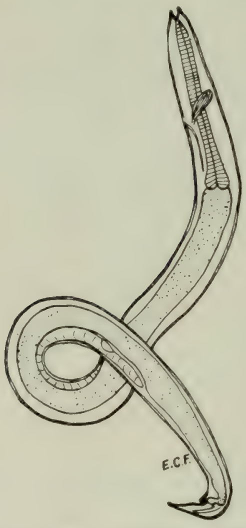

FIG. 223.—Larva of *Ascaris lumbricoides* from trachea of experimentally infected rat eight hours after ingestion of embryonated eggs. × 320. (After Brumpt, Précis de Parasitologie.)

Upon arrival in the intestine of man the larvæ of *Ascaris lumbricoides* originating from a human source develop to adulthood; likewise those in the pig originating from porcine ascarids complete their development. But porcine *Ascaris* larvæ in man and human *Ascaris* larvæ in the pig are apparently unable to complete their development in the reciprocal host. In guinea-pigs, rats and mice, *Ascaris* larvæ from either human or porcine sources, on reaching the intestine after migration through the lungs, are rapidly eliminated. Even in man immature *Ascaris* worms of 1 to 10 cm. length are at times spontaneously evacuated. In the appropriate host the worms reach full maturity two to two and a half months after exposure to infection, and the females begin to lay eggs.

Pathogenicity and Symptomatology.—The lesions produced by the worms and the symptoms occasioned by their presence in the human body may be divided into two periods, (1) the stage of migration and (2) the adult stage of the worm.

1. *The Stage of Migration.*—The minute lesions and petechial hemorrhages produced by the newly-hatched larvæ penetrating through the intestinal wall into the lymphatics and mesenteric

veins, or later *en route* through the liver, are rarely sufficient to produce clinical symptoms. Upon arrival in the lungs the larvæ break out of the capillaries and set up inflammatory processes (Fig. 224). In mild cases there are numerous petechial hemorrhages at the points of emergence into the alveoli. In more heavily infected cases the entire lungs may be ecchymotic and edematous. Micro-

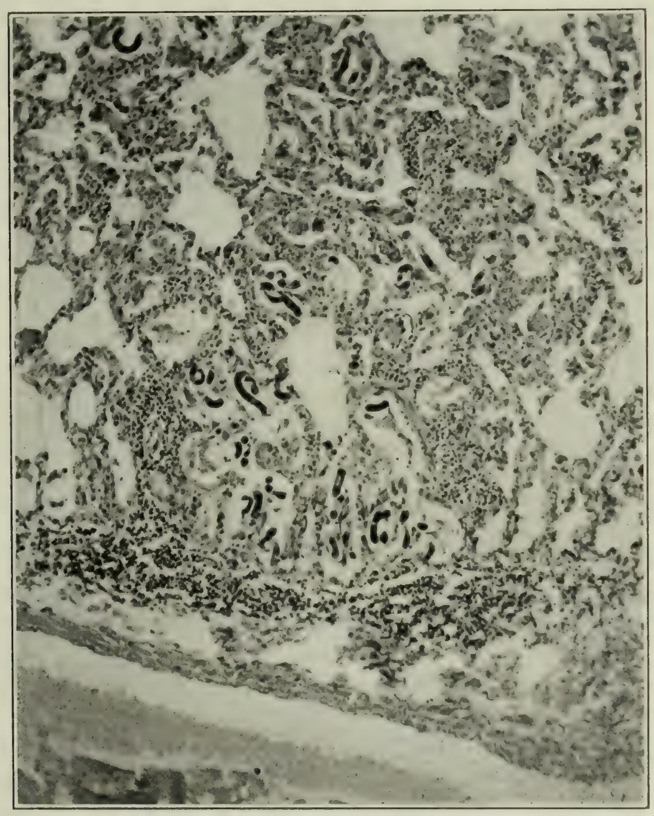

FIG. 224.—Lung of experimentally infected mammal, showing larvæ of *Ascaris lumbricoides* in alveoli and white-cell infiltration around parasitized air spaces. × 100. (Original photomicrograph.)

scopically there are many small inflammatory foci throughout the organ, with a marked exudate into the respiratory passages, consisting of red blood cells, leukocytes, desquamated epithelium, fibrin and migrating larvæ. Local eosinophilia is very marked. The picture is that of profound lobar pneumonia. In extreme cases the lungs may be completely involved, are edematous, hemorrhagic and completely consolidated.

While most of the clinical observations of this stage of the infection have been made on pigs, a few well-controlled experimentally infected human cases are on record, including that of the brothers Koino (1922), who swallowed mature eggs of *A. lumbrocoides* and incurred a serious pneumonia. In such cases respiratory symptoms begin twenty-six hours to four or five days after the ingestion of eggs, the temperature becomes elevated to 39.5° or 40° C., respiration becomes rapid and irregular, coughing is frequent and a typical picture of lobar pneumonia is observed. Ordinarily the symptoms begin to subside after the sixth or seventh day and the patient proceeds to an uneventful recovery. It is altogether probable, however, that in overwhelming infections, cases ordinarily diagnosed as "pneumonia" succumb to the infection. The disease is of sufficient clinical importance to deserve the designation of *Ascaris pneumonia.*

In addition to the lesions produced by *Ascaris* larvæ in the lungs, there are transient microscopic changes in the liver, including small inflammatory foci throughout the organ but not involving the liver cells. Larvæ which get into the general circulation may reach the kidneys, brain, spinal cord and muscles of the heart, where they produce more or less serious lesions. Acute nephritis has been observed in heavy infections, with larvæ in the urine.

In individuals susceptible to *Ascaris* poisoning an urticarial reaction may be developed during the period of migration of the larvæ through the tissues.

2. *The Adult Stage of the Worm.*—Much has been written about the effects of the adult *Ascaris* in the human intestine. The worms normally live in the lumen of the small intestine, feeding on the semi-digested food mass. In infections consisting of only a few worms adults may suffer no inconvenience, but even a single worm may produce digestive disturbances. Infected individuals sensitive to *Ascaris* emanations may develop generalized toxemia or specific nervous complications. Reflex nervous symptoms are particularly common among small children. Large numbers of ascarids in the intestine may become twisted together and cause acute intestinal obstruction. Due to various conditions modifying the normal functioning of the intestinal tract, adult ascarids at times migrate out of the small intestine. They may wander into the stomach and be vomited or may escape through the nares. They may wander up the common duct and obstruct the flow of the bile and pancreatic juices. They may block the lumen of the appendix vermiformis and produce appendicitis. They may even perforate the intestinal wall and occasion peritonitis. Drainage tubes inserted after gastrointestinal operations may also be obstructed by these worms.

Diagnosis.—The presence of adult ascarids can be diagnosed on the basis of finding the fertilized or unfertilized eggs in the stool, except in infections where only male worms are present, a condition

not unique in children. Under the latter circumstances diagnosis may usually be made from disturbed digestion and nervous complications. A diagnosis of *Ascaris* pneumonia, corresponding to the period of larvæ migrating through the lungs, can be made only tentatively, to be checked by examination of the feces some weeks later when the worms become egg-laying adults in the intestine.

Therapeusis.—Santonin and oil of chenopodium are both satisfactory ascaricides. The former drug is slightly less efficient but has the advantage of being less toxic. Routine treatment consists in the following: (1) fasting the previous night and taking an effective cathartic; (2) remaining in bed on the morning of treatment and taking nothing by mouth except water or tea; (3) at 8 A.M. taking one capsule containing 1 grain of santonin powder with an equal amount of calomel or 1 cc. of oil of chenopodium; (4) at 9 A.M. taking 1 grain of santonin or 1 cc. of oil of chenopodium as previously; (5) at 10 A.M. taking 2 ounces of magnesium sulphate or infusion of senna leaves.

In cases of hookworm infection accompanied by ascariasis, carbon tetrachloride in the amount not in excess of 2.8 cc. with 0.2 to 0.5 cc. oil of chenopodium in capsules is not only more effective in removing both species of worms than is either drug alone but produces fewer toxic symptoms.

Surgical interference is indicated where acute obstruction has been produced.

Prognosis.—*Ascaris* infection is not serious except in profound *Ascaris pneumonia,* acute intestinal or biliary-duct obstruction or perforation of the intestine.

Prophylaxis.—Ascariasis is common in all tropical and Oriental countries and in regions of the Occident where primitive methods for disposal of human night-soil prevail. In rural communities, particularly where night-soil is used as fertilizer, the incidence of *Ascaris* infection is higher than in cities, frequently involving 75 to 100 per cent of the population. Vegetables and fruits cannot be sterilized against *Ascaris* by the use of hypochloride of lime but boiling water is a very effective sterilizing agent. As yet no satisfactory method has been found for sterilizing night-soil against *Ascaris* before using it for manurial purposes. Porcine ascarids may produce *Ascaris* pneumonia in man but apparently cannot develop to adulthood in the human host. Immature *Ascaris* eggs, such as those just evacuated in the feces of an infected individual are probably unable to develop on ingestion by man. Undoubtedly human ascariasis results from food or drink contaminated with fully developed *Ascaris* eggs from human sources. The fact should not be overlooked that prenatal infection occasionally results from *Ascaris* larvæ migrating from the lungs of the mother into the fetus. A general program of personal hygiene and community

sanitation, involving the treatment of infected individuals and provision for sanitary latrines, commonly results in the reduction of locations where viable *Ascaris* eggs menace the population.

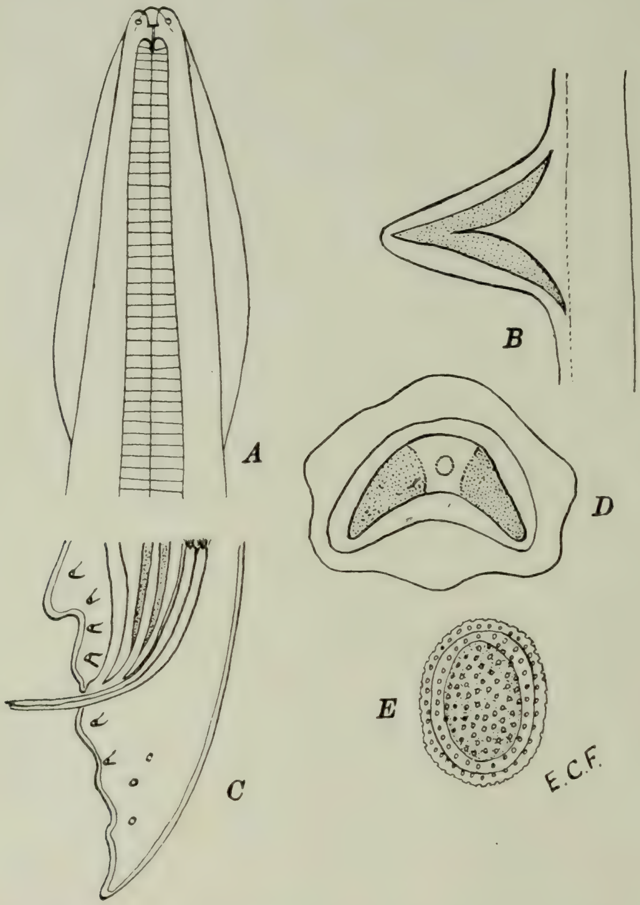

FIG. 225.—*Toxocara canis.* *A*, anterior end of worm, ventral view, showing labia and cervical alæ, × 30; *B*, detail of cross-section through cervical region, showing structure of ala; *C*, posterior end of male, lateral view, showing cloaca, with adjacent portions of rectum, ductus ejaculatorius, copulatory spicules and preanal and postanal papillæ, × 50; *D*, cross-section through spicule, with enveloping sheath; *E*, egg, × 250. (Original.)

GENUS TOXOCARA STILES, 1905.
(genus from τόξον, bow and κάρα, head).

27. **Toxocara canis** (Werner, 1782) Johnston, 1916.

Synonyms.—*Lumbricus canis* Werner, 1782; *Ascaris canis* (Werner, 1782) Gmelin, 1790; *Ascaris mystax canis* (Werner 1782) Blanchard,

1888, Railliet, 1893; *Toxascaris limbata* Railliet and Henry, 1901; *Toxascaris marginata* Leiper, 1907; *Toxascaris canis* (Werner, 1782) Castellani and Chalmers, 1913; *Belascaris canis* (Werner, 1782) Garin, 1913.

This ascarid is a cosmopolitan parasite of the intestine of the dog. It has been recorded at least once from man (Leiper, in Egypt). The males are 4 to 6 cm. long and the females 6.5 to 10 cm. long. The worm (Fig. 225 *A*) is distinguished by having the typical three-lipped oral structure of the Ascaridæ and by possessing cervical alæ or wings, which extend some distance from the anterior end along the lateral margins. These alæ are much longer than broad, and in cross-section (Fig. 225 *B*) have a deeply cleft three-pronged core which supports almost the entire wing structure. There is a series of several pairs of pedunculated and three pairs of sessile papillæ. The spicules are long and curved, slightly unequal, and in cross-section (Fig. 225 *D*) are appreciably convexo-concave. The vulva of the female is situated pre-equatorially. The common uterine tube is very short. The eggs (Fig. 225 *E*) are subglobose to oval in contour, are pitted superficially, and measure 85 to 75 μ respectively in greater and lesser diameters. According to Stewart, Fülleborn, Brumpt, and others the development of the embryo of *Toxocara canis* and its route of migration and subsequent maturity in the ileum of its host parallel the similar stages in the life cycle of *Ascaris lumbricoides*. The dog is practically unaffected by the presence of this worm in its intestine. According to Brumpt three or four months after maturing the worms are eliminated spontaneously from the host, which becomes immune to reinfection. Young puppies frequently acquire this infection prenatally from the mother.

Genus Belascaris Leiper, 1907.

(genus from βέλος, arrow and ἀσκαρίς, helminth).

28. **Belascaris cati** (Schrank, 1788) Railliet and Henry, 1911.

Synonyms.—*Ascaris cati* Schrank, 1788; *Fusaria mystax* Zeder, 1800; *Ascaris mystax* (Zeder, 1800) Rudolphi, 1802; *Ascaris alata* Bellingham, 1839; *Ascaris felis* Glaue, 1909; *Belascaris mystax* (Zeder, 1800) Castellani and Chalmers, 1910.

This is the common ascarid in the intestine of the cat, in which host it is cosmopolitan. It has also been recorded from the wild cat, the lion, the leopard, *Felis minuta* and *F. maniculata*. There are 9 recorded cases of this infection from the human host (Europe, North America). The adult worms (Fig. 226 *A*) are characterized by having, on the border of the cervical region, a heart-shaped lateral wing which is relatively broad and only about three times as long as broad. In cross-section (Fig. 226 *B*) the core of the wing is found only in its outer half; it is triangular, but not deeply cleft

as is that of *Toxocara canis*. The males measure 4 to 6 cm. long and the females 4 to 12 cm. long. The posterior end of the male (Fig. 226 *C*) is provided with pedunculated sessile papillæ as in

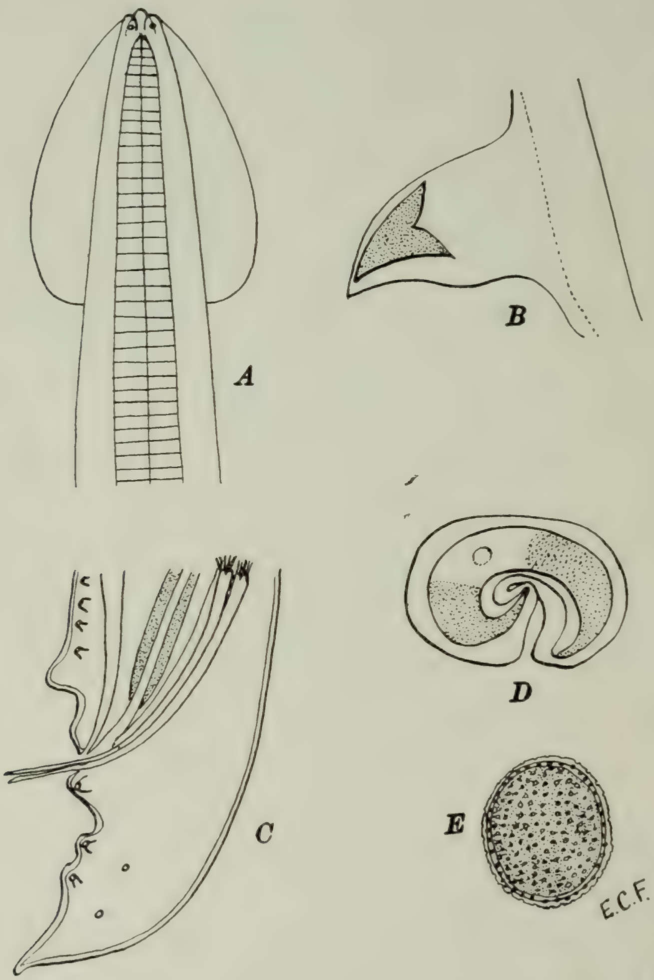

Fig. 226.—*Belascaris cati.* *A*, anterior end of worm, ventral view, showing labia and cervical alæ, × 30; *B*, detail of cross-section through cervical region, showing structure of ala; *C*, posterior end of male, lateral view, showing cloaca, with adjacent portions of rectum, ductus ejaculatorius, copulatory spicules and preanal and postanal papillæ, × 50; *D*, cross-section through spicule with enveloping sheath; *E*, egg, × 250. (Original.)

T. canis, but the topographic arrangement is somewhat different. The copulatory spicules are subequal, measure 1.7 to 1.9 mm. in length and in cross-section (Fig. 226 *D*) are seen to have their lateral

margins infolded on themselves so as to form a spicular trough. The vulva of the female is situated in the anterior fourth of the body. The common uterine duct is long. The eggs (Fig. 226 *E*) are subglobose, thin-shelled, delicately pitted, and measure 65 to 75 μ in diameter. They are very resistant to desiccation and other unfavorable conditions of the environment. In water or moist earth the embryos *in ovo* develop into rhabditiform larvæ, which, on ingestion by the appropriate host, are believed to parallel *Ascaris lumbricoides* in their course of migration and subsequent maturity, although this phase of the life cycle of *Belascaris cati* has not been carefully studied. The worms provoke little if any reaction on the part of their hosts.

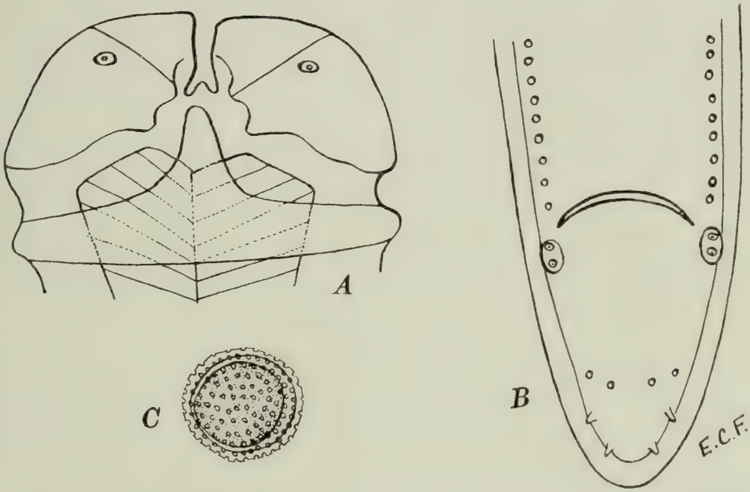

FIG. 227.—*Lagochilascaris minor.* *A*, anterior end, showing the two ventral lips and the intervening ventral groove; *B*, posterior end of male, ventral view, showing cloacal opening and adjacent papillar pattern; *C*, egg, × 250. (After Leiper, Proc. Zoöl. Soc. London.)

GENUS LAGOCHILASCARIS LEIPER, 1909.

(genus from λαγώχειλος, hare-beaked and ἀσκαρίς, helminth).

29. **Lagochilascaris minor** Leiper, 1909.

Synonym.—*Lagocheilascaris minor* Leiper, 1909 of Fantham, Stephens, Theobald, 1916.

The normal habitat of this worm is the intestine of the cloudy leopard, *Felis nebulosa.* Specimens of this species, sexually mature, have been recovered from subcutaneous abscesses in the neck, in the vicinity of the angle of the jaw, in the orbit, and in tonsillar abscess pockets in 4 natives of Trinidad. The worm has also been recovered from a mastoid abscess of a patient in Dutch Guiana.

The male worms measure 9 mm. in length by 0.4 mm. in transverse diameter and the females, 15 mm. in length by 0.5 mm. in thickness. The parasites lack cervical alæ but have a triangular keel-like cuticular ledge along practically the entire extent of each lateral line. The three large lips are covered by a heavy investment of cuticle, each one having a distinct vertical cleft, the entire labial structure being separated from the body by a deep annular furrow (Fig. 227 *A*). The male has about 24 pairs of preanal papillæ and 1 double pair and 4 single pairs of postanal papillæ (Fig. 227 *B*). The copulatory spicules are solid colorless rods measuring 0.35 mm. and 0.4 mm. respectively in length. The vulva is preëquatorial in position. The unbranched portion of the uterine tube is directed anterior from its vulvar opening. The ovaries and uteri lie in the middle third of the body. The eggs (Fig. 227 *C*) are globose, clear in color, thick-shelled, and have superficial pittings like those of *Belascaris cati*. They measure 65 μ in diameter. Nothing is known about the life cycle of this nematode, but infection is probably direct, the worms in the human host becoming lodged in abnormal foci during their migration route through the body and developing there into mature specimens.

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CHAPTER XXVII.

MYOSYRINGATE NEMATODES (CONTINUED).

SPIRUROID AND DIOCTOPHYMOID FORMS.

Suborder Spirurata Railliet and Henry, 1915.

THIS suborder contains an assemblage of species of diversified types, but having the common characteristics of being long and attenuate, with a slender esophagus lacking a cardiac bulb. The females are larger than the males. The life cycle involves one or more intermediate hosts. Human representatives are found in the superfamilies **Spiruroidea** Railliet and Henry, 1915, **Dioctophymoidea** Railliet, 1915, and **Filarioidea** Weinland, 1858.

SUPERFAMILY SPIRUROIDEA RAILLIET AND HENRY, 1915.

(SPIRUROID FORMS.)

This superfamily comprises those species of filariform or slightly more robust type, with or without oral labia, having an esophagus consisting of an anterior muscular portion and a posterior glandular region; an intestine without diverticula; caudal alæ commonly present in the male; copulatory spicules usually unequal; and vulvar opening frequently equatorial in position. The species parasitic in man are grouped in the families **Spiruridæ** Oerley, 1885, **Gnathostomatidæ** Blanchard, 1895, **Physalopteridæ** Leiper, 1908 and **Thelaziidæ** Railliet, 1916.

Family SPIRURIDÆ Railliet and Henry, 1915.

The members of this family possess two or four trilobed lateral lips, and at times accessory ventral labia. There is a chitinized oral vestibule in front of the esophagus. In the male the well-developed caudal alæ are supported by pedunculated papillæ. The females are oviparous. The adults are parasitic in the tissues of the digestive tract of vertebrates. The eggs contain mature larvæ at the time of oviposition. The worms require an intermediate insect host, in the tissues of which the larvæ become encysted. Cases of human infection with spirurid nematodes have all been diagnosed as belonging to the genus *Gongylonema*. These worms should probably all be designated as *Gongylonema pulchrum*.

Genus Gongylonema Molin, 1857.
(genus from γογγύλος, round and νημα, thread).

30. **Gongylonema pulchrum** Molin, 1857.

Synonyms.—*Filaria labialis* Pane, 1864; (?) *Filaria scutata* Leuckart, 1873; (?) *Spiroptera scutata* (Leuckart, 1873) Korzil, 1877; (?) *Gongylonema scutatum* (Leuckart, 1873) Railliet, 1892; (?) *Myzomimus scutatus* (Leuckart, 1873) Stiles, 1892; *Gongylonema ursi* (Dujardin, 1845) Neumann, 1894.; *Gongylonema confusum* Sonsino, 1896; *Gongylonema subtile* Alessandrini, 1914; *Gongylonema hominis* Stiles, 1921; (?) *Gongylonema ransomi* Chapin, 1922.

Status of the Gongylonemate Nematodes.—The status of the gongylonemate nematodes secured from various definitive hosts is very unsatisfactory, due to disagreement of various investigators as to what characters may be relied upon for species differentiation in this genus. Thus there may be one to six different species in the group placed with some hesitancy by the present author in the species *Gongylonema pulchrum*, while Baylis (1925) considers *G. filiforme* Molin, 1857, *G. spirale* Molin, 1857 and even *G. neoplasticum* Fibiger and Ditlevsen, 1914 as possibly synonymous with *G. pulchrum*. Difficulty in specific identification has resulted from size variation of the worms, in the different definitive hosts, in the range of size of the copulatory spicules in the male worms, and in the fact that the only well-described specimens obtained from human cases were immature females. The worm lives almost invariably in the upper portion of the digestive tract of its host (mouth, esophagus, stomach), where it forms sinuous galleries in the mucous membrane and subdermal connective tissue. It has been recovered from the following hosts: (*G. pulchrum sensu stricto*) wild boar, domestic pig, ox, horse, donkey, macaque, Algerian hedgehog; (*G. scutatum*) ox, zebu, horse, sheep, goat, dromedary, macaque, Algerian hedgehog; (*G. ursi*) polar bear; (*G. confusum*) horse; (*G. ransomi*) American pigs; (*G. labialis*) man; (*G. subtile*) man; (*G. hominis*) man. The size of the worm varies considerably according to the host in which it is found.

Structure and Life Cycle of the Worms.—Some authors regard ruminants, in which the parasite develops to a maximum size, as the optimum hosts and the pig and man as somewhat less suitable for its complete development. The male reaches a maximum length of 62 mm. by 0.15 to 0.3 mm. in diameter and the female, 145 mm. by 0.2 to 0.5 mm. The anterior extremity (Fig. 228 *A*, *B*) is covered by a variable number of bosses or scutes, usually arranged in about eight longitudinal series, two rows in each of the four submedian fields. A pair of small lateral cervical papillæ, one on each side, is found about 0.1 to 0.2 mm. from the anterior extremity. Slightly behind these there arises a pair of cervical alæ which ter-

minate a short distance in front of the posteriormost cuticular bosses. The entire cuticle is characterized by the possession of fine transverse striations. The mouth is small and is provided with a

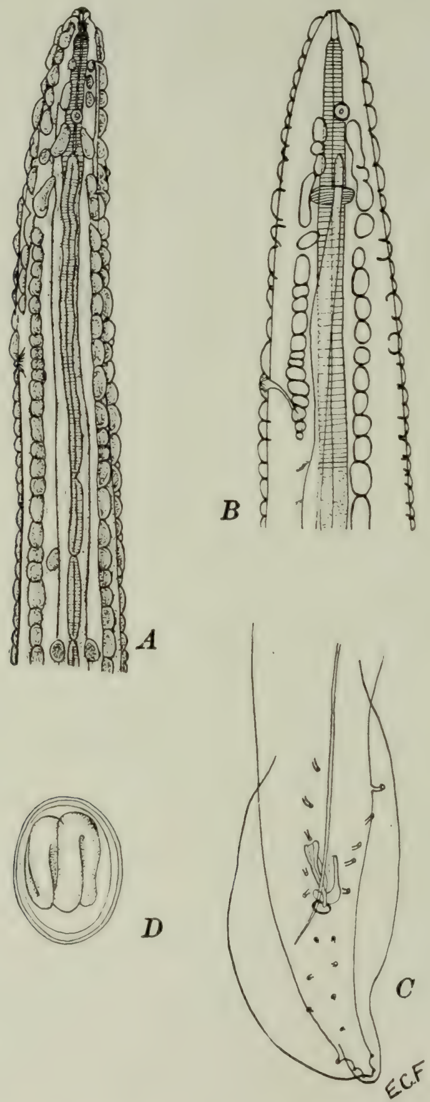

FIG. 228.—*Gongylonema pulchrum.* *A*, anterior end of worm from human host, lateral view, × 76 (after Ward, in Journal of Parasitology); *B*, anterior end of worm from reservoir host, lateral view, × 80 (after Baylis); *C*, posterior end of male, ventral view, showing alæ, caudal papillæ, spicules and gubernaculum, × 80 (after Baylis); *D*, egg, with coiled larva, × 375. (After Fibiger.)

funnel-shaped cuticular rim, immediately behind which there is believed to be a group of six minute cephalic papillæ. The buccal vestibule consists of a short capillary tubule varying from 40 to 80 μ in length. The anterior portion of the esophagus is a cylindrical muscular tube; the posterior portion is longer and stouter and has glandular walls. The excretory pore is situated in a small crater-like projection of the cuticula on the ventral side a short distance in front of the junction of the two portions of the esophagus.

The caudal end of the male (Fig. 228 *C*) is provided with distinct lateral alæ, which are appreciably asymmetrical, the member on the left side arising further anteriad and also extending around the caudal tip. There are from 2 to 8 (usually 5) pairs of subventral pedunculated preanal papillæ, 4 pairs of subventral pedunculated postanal papillæ and usually 4 pairs of minute papillæ at the caudal extremity. The two copulatory spicules are extremely unequal in length and dissimilar in appearance. The left spicule is long (4 to 23 mm.) and narrow, with a tubular shaft and narrow membraneous alæ. The right spicule is short (not over 0.18 mm.) and broadly winged. The gubernaculum has a V-shaped anterior portion and an expanded posterior part. The posterior end of the female is asymmetrically bluntly conical. The vulva is thick-walled and is slightly protuberant, being situated some little distance in front of the anus, which is subterminal. The vagina is very long, extending anteriad from the vulva to the equatorial region. The divergent uteri extend nearly to the extremities of the worm, where they join the slender oviducts and these latter, in turn, the capillary ovaries. The transparent thick-shelled oval eggs (Fig. 228 *D*) are embryonated when laid. They measure from 50 to 70 μ in length by 25 to 37 μ in lesser diameter.

When evacuated in the feces of the host the eggs remain dormant until swallowed by an appropriate insect, whereupon they hatch in the digestive tract of this insect, perforate through the intestinal wall into the body cavity and become encapsulated. They normally reach the definitive host again by being ingested along with the insect host. Ransom and Hall (1915) have shown experimentally that several species of dung beetles of the genera *Aphodius* and *Onthophagus* as well as the small cockroach, *Blatella germanica* serve as intermediate host of the form *G. scutatum*, while Baylis, Sheather and Andrews (1925) have demonstrated that the feeding of naturally-infected dung beetles (*Onthophagus taurus*, *Caccobius schreberi*, *Aphodius fimetarius* and *Sphæridium* sp.), as well as experimentally-infected *Blatella germanica* to sheep, and of experimentally-infected *Blatella germanica* to calves and pigs, produce typical infections in the esophageal wall of the mammalian host. Once within the digestive tract of the definitive host the larvæ probably burrow into the wall of the stomach or duodenum and migrate along the wall of

the tube up to the esophagus or oral cavity. Baylis (1925) has demonstrated that the larvæ do not migrate through the blood stream.

Further cross-experimental work of an extensive character is required in order to determine whether the gongylonemate nematodes from these several hosts are one and the same species or whether there are morphological or physiological grounds for regarding at least some of them as closely related but distinct species.

Pathogenicity and Symptomatology.—In non-human mammalian hosts the gongylonemate worms are found in burrows of the mucosa and submucosa of the mouth, including the tongue, and of the esophagus. The 7 human cases (Pane, 1; Alessandrini, 1; Ward, 1; Stiles, 3; Ransom, 1) all involve the oral cavity, 4 cases being from the lips, 1 case (two worms) from the anterior pillar of the tonsil and from the angle of the jaw, and 2 cases from the "mouth." Five of these patients were native white women from the Southern United States (Arkansas, Georgia, Florida, Virginia, Louisiana) and the other 2 were native Italians (Naples, Rome). The parasites in the human cases were described as actively migrating back and forth in the subdermal connective tissue, the outlines of their burrows being visible to the naked eye. They were disposed to travel from the lips to the fauces and back again. The movement was so rapid as to require considerable skill in removing them. In none of the human cases was there an indication of the worms migrating to the esophagus, which is the more usual habitat in ruminants. The patients harboring the parasites were conscious of their presence and of their migrations. In one case the worm may have been directly or indirectly responsible for an acute pharyngitis and stomatitis. In at least two of the patients severe nervous symptoms, which accompanied the presence of the worms, disappeared as soon as the parasites had been removed. It seems probable, therefore, that both local and indirect symptoms are produced by the presence of these worms in the oral mucosa or subdermal connective tissue. There is no evidence, however, that *Gongylonema pulchrum* produces neoplasms of the digestive mucosa such as *G. neoplasticum* and *G. orientale* have been found to do.

Diagnosis.—The presence of these thread-like worms actively migrating through subdermal tunnels of the oral cavity suggests the possibility of gongylonemate nematodes. Specific diagnosis can be made only after the worms have been removed and carefully examined under the microscope.

Therapeusis.—The worms may be removed by skillful insertion of a needle under the worms when they come close to the surface in the region of the thin labial mucosa. In one case an antiseptic mouth wash containing thymol stimulated the worm to work its way out of its tunnel, so that it was easily removed with the fingers.

Prophylaxis.—Infections in man like those of other mammals are probably incurred from accidental ingestion of infested insects, the cockroach, *Blatella germanica* being the most likely human contact. However the possibility must not be overlooked that larvæ migrate out of disintegrating cockroaches and may be swallowed in contaminated water. In human cases prevention is a matter of personal hygiene.

Family GNATHOSTOMATIDÆ R. Blanchard, 1895.

The species of this family are characterized by having a cuticular cephalic bulb, provided either with conspicuous transverse striations or rows of posteriorly directed hooklets. The mouth possesses a pair of large trilobed lateral lips, with thickened cuticular surfaces, each member of the pair being opposed to its mate. Opening into the periesophageal region of the head are the ducts of the two (or at times three?) pairs of long club-shaped cervical glands. The male has four or more pairs of papillæ supporting the caudal alæ, and two spicules. The vulva of the female is postequatorial; the vagina is directed anteriad. The females are oviparous. The eggs are thin-shelled and sculptured. Two species of the genus *Gnathostoma* (*G. spinigerum* and *G. hispidum*) have been reported from man.

Genus Gnathostoma Owen, 1836.

(genus from *γναθος*, jaw and *στομα*, mouth).

31. **Gnathostoma spinigerum** Owen, 1836.

Synonyms.—*Cheiracanthus robustus* Diesing, 1836; *Cheiracanthus siamensis* Levinsen, 1890; *Gnathostoma siamense* (Levinsen, 1890) Railliet, 1893.

Historical.—This worm was first reported by Owen from stomach nodules of the tiger. It has likewise been reported from the domestic cat, the wild cat and the leopard, as well as from the dog, in India, the Malay States, China and Japan. In these hosts the worm is usually found in the stomach wall, in the midst of an indurated nodule, or occasionally in the body cavity. Yoshida's report (1926) of 3 cases of a gnathostome in esophageal tumors of *Putorius itatsi* from Japan may also be referable to this species. The first human infection was described by Levinsen (1890), who studied a single immature female specimen obtained by Deuntzer from a breast abscess of a native woman from Siam. In 1909 Leiper reported a second case, also from Siam, the worm in question being an immature male which had been removed by Kerr from a cutaneous node. Additional human cases have been described from the Malay States (1), Japan (1), and China (4), in all of which the worms were obtained from peripheral abscesses or while migrating under the skin. The only reference to human beings harboring the adult worms in

the intestinal tract is that of Chandler (1927) who on two occasions found eggs of *Gnathostoma spinigerum* in examination of stools, presumably human, from Burma and Eastern Bengal, where the infection is very common in cats.

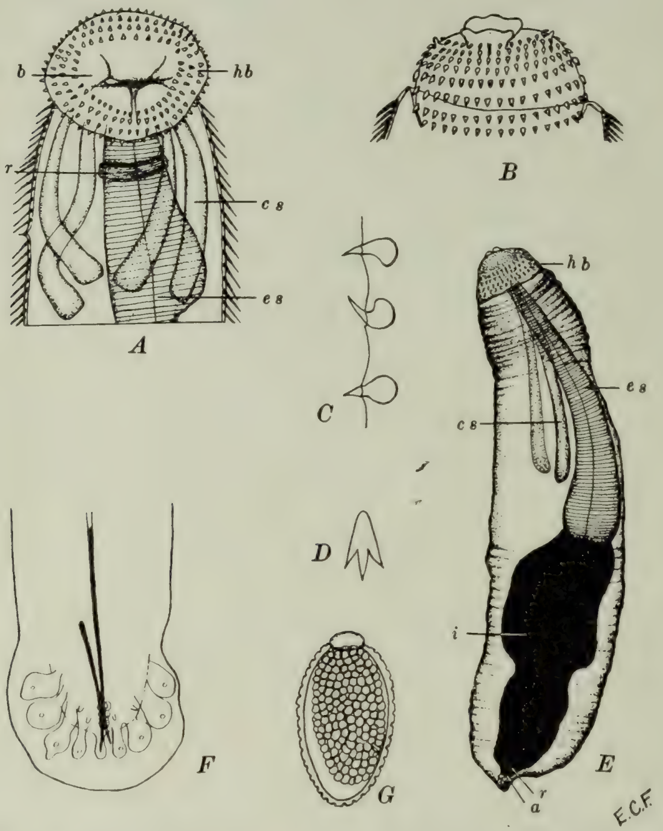

FIG. 229.—*Gnathostoma spinigerum.* *A*, anterior end of immature worm, showing cephalic bulbus with four rows of hooklets and cervical salivary glands, ventral view, × 100 (after Morishita and Faust, Journal of Parasitology); *B*, head end of more mature worm, with eight rows of hooklets, lateral view, × 100 (original); *C*, detail of hooklets of head; *D*, detail of body spine; *E*, immature worm, lateral view, showing salient features; *hb*, head bulbus, *es*, esophagus, *cs*, cervical salivary glands of right side, *i*, intestine filled with food, *r*, rectum, *a*, anus, × 40 (adapted from Morishita and Faust, Journal of Parasitology); *F*, posterior end of male worm, ventral view, showing papillæ and spicules, × 40, (adapted from Baylis and Lane); *G*, egg of *G. spinigerum* from feces of naturally infected cat, × 333. (After Faust, Journal of Parasitology.)

Structure of the Adult Worms.—The adult worms in the type host (*Felis tigris*) reach a length of 11 to 25 mm. for males and 25 to 54 mm. for females. In dogs the worms are somewhat smaller and in cats even more restricted in size. The females are also stouter than

the males. They are robust nematodes, reddish in color and slightly transparent, with a globular cephalic swelling separated from the rest of the body by a cervical constriction (Fig. 229 *B*). The oral end is frequently curved ventrad while the posterior end is strongly recurved ventrad and inward. In tumors of the intestinal tract, the worms are tightly coiled within the cavity of the nodule, which contains one or more adult individuals. The anterior half of the worm's cuticula is provided with leaf-like spines, which are most common in the region immediately behind the cervical region and become less conspicuous toward the equatorial region. The anteriormost spines (Fig. 229 *D*) have three sharp terminal points while the posteriormost ones are narrower and have only a single point. The posterior part of the body is entirely devoid of spines and the cuticle is entirely smooth. Superficial annular creasing of the body is common. The globular cephalic portion of the worm bears two large fleshy lips that guard the mouth. The head portion is covered with four to eight transverse rows of simple, sharply-pointed, recurved hooks (Fig. 229 *C*). The mouth opens directly into the esophagus, a large muscular tube, which extends several millimeters posteriad and in young specimens (Fig. 229 *E*) may reach to the equatorial plane. This is followed by the intestine, which communicates posteriad with a short conical rectum, the latter opening through the anal pore a short distance in front of the caudal tip (Fig. 229 *E*). Four large club-shaped cervical secretory glands (Fig. 229 *A*, *E*, *cs*) are arranged symmetrically around the esophagus. They lie in the body cavity and their ducts fuse in pairs on either side of the head to discharge through a common duct that perforates the adjacent lip. In the male (Fig. 229 *F*) the posterior end has a cuticular expansion surrounding the genital apparatus. There are four pairs of nipple-shaped papillæ around the cloaca. The spicules are unequal solid chitinous rodlets measuring 1.1 mm. and 0.4 mm. respectively. The vulva in the female worm lies a short distance behind the equatorial plane. There is a long anteriorly directed vagina, which divides into two uterine tubes. The eggs (Fig. 229 *G*) are transparent oval objects, with a sculptured shell and a mucoid plug at one pole. They measure 65 to 70 μ in length by 38 to 40 μ in transverse diameter and are in the morula or gastrula stage of development when oviposited.

The Life Cycle of Gnathostoma.—The life cycle of *Gnathostoma spinigerum* is still obscure, but Chandler (1925) has shown that larval gnathostomes, which are normally encysted on the mesentery of the Rock Python (*Python reticulatus*) and the King Cobra (*Naja bungarus*) as well as the common cobra (*N. tripudians*), may be transmitted to cats, where they form burrows in the liver, or become imbedded in the parietal peritoneal wall or the renal capsules. These larvæ in the cat are considerably larger than the ones in the

reptilian host, but resemble the former in every other respect. They differ from adult *Gnathostoma spinigerum* in having only four instead of eight rows of transverse cephalic hooklets, and in this respect agree with the larval forms described by Morishita and Faust (1925) from peripheral lesions in the human host. Chandler (l. c.) suggests that the worms only attain the full complement of cephalic hooklets after a final moult. It is significant to note that the worms described by Leiper (1909) and Tamura (1921) from peripheral foci in man were provided with eight rows of cephalic hooklets, and in both size and structure were practically mature.

Pathogenicity and Symptomatology.—Lesions produced in the intestinal wall, primarily in the stomach, have been described only from non-human hosts. They consist of indurated nodules formed of host tissue around one or more mature or maturing worms, which lie free in an abscess pocket in the center of the tumor. The worms are bathed with a milky purulent exudate. There is frequently a pore from this pocket opening into the intestinal lumen, through which eggs laid by the adult females are discharged. There is no evidence of malignancy in the tumor wall. This type of lesion is referred to as *gnathostomiasis interna.* The peripheral lesions are dermal or subdermal in position and consist either of indurated nodules with abscessed centers or tunnels between the epidermis and corium, with infiltration of large numbers of eosinophils and lesser numbers of plasma cells. An infection consisting of such peripheral lesions is designated as *gnathostomiasis externa.* The development of the immature worms in peripheral abscess pockets or their migration in tunneled passages under the superficial layers of the skin produces extreme discomfort, consisting of intermittent pricking pain and continued dull pain similar to that produced by furunculosis.

Diagnosis.—Specific diagnosis can only be arrived at after removal of the worm and study of its peculiar structure.

Therapeusis.—In *gnathostomiasis externa,* this consists in excision of the worm with its surrounding abnormal tissue. Therapeutic procedure for *gnathostomiasis interna* has not been studied.

Prophylaxis.—No statement with respect to prophylaxis can be made until the life cycle has been fully elucidated. It seems altogether likely that man is not the optimum host of the worm. It is problematical whether the larvæ, which undoubtedly require an insect host, enter the body *via* the skin or by way of the mouth, although the latter route is the common one for those members of the superfamily **Spiruroidea,** for which the life cycle is known.

32. **Gnathostoma hispidum** Fedtschenko, 1872.

Synonyms.—*Cheiracanthus hispidus* (Fedtsch., 1872) Csokor, 1882; *Cheiranthus hispidus* (Fedtsch., 1872) v. Linstow, 1893.

Gnathostoma hispidum is a relatively common parasite of the stomach wall of wild and domesticated pigs in Central and Eastern Europe. It has also been reported from this host from Turkestan, India, Annam, Japan, China and the Congo. It has been found once in a cow (Berlin). A single human infection has been described from Tokyo, Japan, in a progressive linear swelling of the left thenar eminence. A young female worm was removed from the lesion.

The adult worms of this species differ from *G. spinigerum* in being somewhat larger and more robust, in having twelve transverse rows of hooklets on the cephalic bulbus instead of eight, in having multidigitate body spines which extend to the caudal extremity, and in having only one pair of small ventral alal papillæ on the male.

The clinical aspects of *gnathostomiasis hispida* are similar to those of *gnathostomiasis spinigera.*

Family PHYSALOPTERIDÆ Leiper, 1908.

The species of this group have a bilabiate mouth with teeth on the inner surface of the labia. The cuticula is reflected over the cephalic extremity to form a collarette. An oral vestibule is lacking or very inconspicuous. The male worm has well-developed caudal alæ, frequently meeting ventrally over the cloaca, and supported by long pedunculated papillæ with knobbed ends. The vulva of the female is preëquatorial. The eggs are transparent, thick-shelled objects and are embryonated at oviposition. Recent studies by Ortlepp (1926) indicate that only one member of this family has thus far been found as a human parasite.

Genus Physaloptera Rudolphi, 1819.
(genus from φυσαλίς, bubble and πτερον, wing).

33. **Physaloptera caucasica** v. Linstow, 1902.

Synonym.—*Physaloptera mordens* Leiper, 1907.

This nematode was first obtained by Ménétriés from the ileum of a patient in the Caucasus. It was also obtained by Leiper in a native child in Uganda. Later Leiper and Turner found it to be quite common in natives of Tropical Africa. It lives attached to the wall of the intestine all the way from the esophagus to the ileum. Turner has also recovered occasional specimens from the liver. Leiper believes monkeys, which harbor the infection in Africa, are the reservoir hosts. The worms are of considerable size, the males measuring 14 to 50 mm. in length by 0.7 to 1.0 mm. in breadth and the females, 24 to 100 mm. by 1.14 to 2.8 mm. In shape and general appearance they resemble immature *Ascaris lumbricoides,* but are readily distinguished by several important features. The body tapers very gradually anteriorly and ends bluntly. In the female

it tapers posteriorly to a sharp tip. The anterior end (Fig. 230 *A*) is surrounded by a reflected portion of the cuticula, which forms a collarette around the head. The mouth is surrounded by two fleshy lips, which are oblong in shape and lateral in position (Fig. 230 *B*, *C*). Each lip is provided on its median aspect with a series of dental processes, consisting of a middle single-pronged tooth which

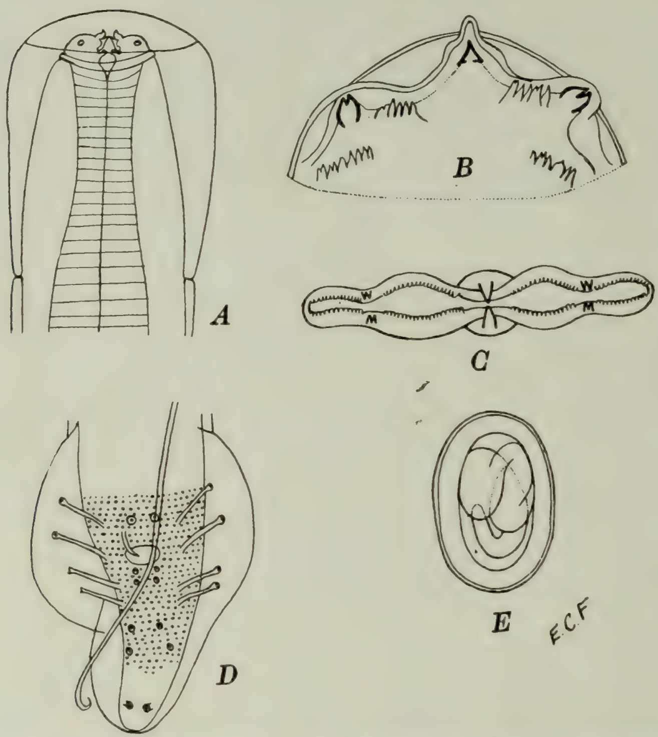

FIG. 230.—*Physaloptera caucasica.* *A*, anterior end of worm showing cuticular collarette, × 37 (after Leiper, Trans. Royal Soc. of Med. and Hyg.); *B*, lateral view of inner lip, showing dental processes, ×250 (after Ortlepp, Journal of Helminthology) *C*, head-end view of inner lips, showing dental processes, × 250 (after Schulz, Annales de Parasitologie); *D*, caudal end of male worm, showing asymmetrical alæ, pedunculated and sessile papillæ and spicules, × 27 (adapted from v. Linstow) *E*, embryonated egg of *P. caucasica*, × 375. (After Schulz, Annales de Parasitologie.)

is immediately apposed to a similar prong from the other lip, two double-pronged teeth similarly apposed, and a considerable number of intermediate minute denticles. Each lip also bears two conspicuous submedian papillæ, the four papillæ being situated in a quadrangular position. The bursa copulatrix (Fig. 230 *D*) is composed of asymmetrical alæ, of which the right member is shorter and

slightly broader, and the left member passes around the caudal extremity and terminates just in front of the posterior margin of the right. Typically there are 4 pairs of pedunculate papillæ and 6 pairs of sessile or subsessile ones, arranged as in the accompanying diagram (Fig. 230 *D*). An additional preanal pair may also be present. The pericloacal cuticula is transversely bossed. The spicules are unequal capillary rods, gradually tapering distally to a point, and commonly curled distally. The left one has a length of 3.2 to 5.5 mm. and the right one, of 0.476 to 0.62 mm. The vulva of the female opens in the vicinity of the posterior limit of the esophagus. The vagina leads posteriad, becoming swollen in its more distal portion into an egg chamber. Just behind this region it reflexes on itself and soon bifurcates twice to form four uterine tubules. Two of these uteri with their oviducts and ovarian tubules are situated anteriorly and two, posteriorly. The eggs (Fig. 230 *E*) are smooth thick-shelled transparent oval objects, having a range of measurement of 44 to 65 μ (length) by 32 to 45 μ (breadth). The eggs *in utero* contain mature larvæ.

The life cycle of *Physaloptera caucasica*, like that of other species of this family, is unknown, but it is believed that insects serve as intermediate hosts.

The clinical and preventive aspects of this infection have not been studied.

Family THELAZIIDÆ Railliet, 1916.

Members of this family lack definite lips but usually possess a short buccal capsule. The caudal end of the male is conspicuously recurved and may or may not have alæ but is usually provided with preanal and at times postanal papillæ. The eggs when laid are fully embryonated. Adults live in the orbital, nasal or oral cavities of mammals and birds, in the air-sacs of birds or the intestine of fishes. An intermediate insect host is probably required. A species of the type genus, *Thelazia*, has been reported from man.

Genus Thelazia Bosc, 1819.
(genus from θηλάζω, to suck).

34. **Thelazia callipæda** Railliet and Henry, 1910.

This worm was first described by Railliet and Henry (1910) from a single female specimen recovered from the nictitating membrane of a dog in Rawal Pindi (Punjab). Since that time it has been found a number of times in the conjunctival sac of dogs in the Punjab, Burma, Central and North China. It has been recorded once as a natural infection in the rabbit (Faust, 1927). There are three records of *Thelazia callipœda* in man, consisting of two infections with the adult worms in the conjunctival sac (Stuckey, 1917, in

a Peking coolie; Trimble, 1917 in a Fukienese farmer), and one with larvæ in an advanced stage of development attached to the epithelial layer of a wart-like papilloma of the lower eyelid of a western physician in Chengtu, Szechuan (Howard, 1927).

The adult worms are creamy- or ivory-white in color, cylindrical in shape and tapering at both ends; they range in size from 8.5 to 13 mm. by 0.25 to 0.75 mm. for males and 7 to 17 mm. by 0.5 to 0.85 mm. for females. The entire cuticula is plaited into well-defined transverse striations of about 3 to 4 μ intervals these having sharp edges. The oral end lacks labia but may have four or more

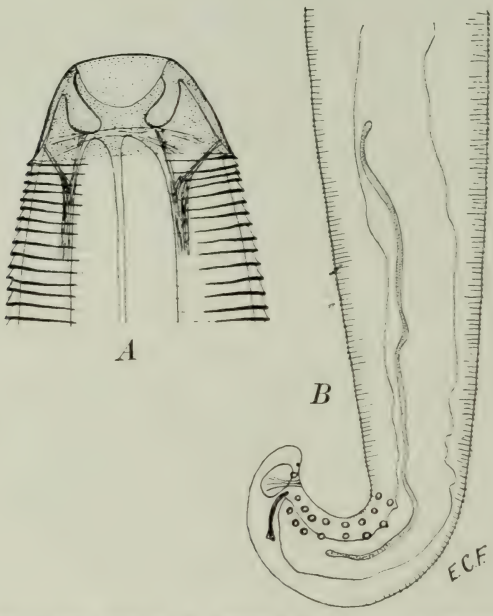

Fig. 231.—*Thelazia callipæda.* *A*, anterior end of worm, showing buccal capsule and cuticular plaiting, × 350; *B*, posterior end of male worm, showing preanal and postanal papillæ and copulatory spicules, × 55. (After Faust, Journal of Parasitology.)

submedian sessile papillæ. The buccal capsule (Fig. 231 *A*) is discontinuous ventrally but is continuous over the dorsum. Distinct ventral, lateral and dorsal elements may be distinguished. The male (Fig. 231 *B*) has a conspicuously recurved posterior end. There are 6 to 8 pairs of sessile preanal papillæ and 2 similar pairs in a postanal position. The copulatory spicules are two in number, one being short and rigid, slightly twisted, club-shaped, with curved lateral alæ along the entire length, and one, very long, rod-shaped, and commonly less rigid. The vulva of the female opens ventrally a short distance behind the equatorial plane of the esophagus.

The vagina is directed posteriad, as is the outer portion of the uterus, which originates as a single stem just behind the ovejector, later dividing into two arms, which parallel one another in complicated coiling in the posterior half of the body. The corresponding oviducts and ovaries are also situated in the posterior part of the worm. The eggs are embryonated when laid, are at first oval and measure 54 to 60 μ by 34 to 37 μ, but their capsule soon enlarges into a spherical surface, with a finger-like evagination on one side into which the larva crawls. The life cycle of the worm has not been elucidated but an intermediate arthropod host is probably required.

Pathogenicity and Symptomatology.—The worms live in the conjunctival sac of the host. Ordinarily they produce little conjunctivitis but stimulate a secretion of lacrymal fluid. In dogs which become reinfected every summer the surface of the eyeball becomes gradually opacified by the intermittent gliding of the worms across its surface. Presence of the adult worms in the human eye may possibly be responsible for paralysis of the muscles of the lower eyelid and cause ectropion (Trimble, 1917). The presence of the worms in the conjunctival sac is accompanied by intense pain and gives rise to extreme nervous symptoms.

Diagnosis.—The creamy-white thread-like worms which crawl out from the conjunctival sac over the eyeball may be removed with eye forceps and examined under the microscope.

Therapeusis.—Instillation of 2 per cent cocaine solution into the conjunctival sac of an infected member will cause the worms to crawl out of the inner canthus of the eye, allowing their removal with eye forceps within a few minutes.

Prophylaxis.—Since man is only an incidental host and the dog the reservoir of the infection, human beings presumably acquire the infection through association with infested dogs, although direct infection is probably not possible. Epidemiological data indicate that the infective larvæ are transferred to the mammalian host during the summer months, possibly by the accidental ingestion of the appropriate arthropod (?) host.

Superfamily Dioctophymoidea Railliet, 1916.

(Dioctophymoid Forms.)

This group of spirurate nematodes consists of species of medium or very large size. The cuticle is relatively transparent and is transversely striated at the extremities. The mouth is non-labiate but is provided with 6, 12 or 18 papillæ in one or two circles. The esophagus is long and lacks a posterior bulbus. The male worm has a bell-shaped bursal cup, which lacks supporting rays. There is a single copulatory spicule. The anus of the female is at the extreme posterior end. The vulva is either near the anus or in the anterior

28

part of the body. The vagina is very long. Only one ovarian tubule is present. The eggs are usually pitted except at the two poles. The adult worms live in the digestive tract of birds or in the body cavity or kidney of mammals. All species of this superfamily thus far described belong to the type family **Dioctophymidæ** Railliet, 1915. Of the three recognized genera of this family, one species, *Dioctophyme renale* has been reported as a human parasite.

Genus Dioctophyme Collet-Meygret, 1802.

(genus from *διογθῶ*, to swell, and *φῦμα*, tubercle).

35. **Dioctophyme renale** (Goeze, 1782) Stiles, 1901.

Synonyms.—*Ascaris renalis* Goeze, 1782; *Ascaris canis et martis* Schrank, 1788; *Ascaris visceralis* Gmelin, 1790; *Strongylus gigas* Rud., 1802; *Strongylus renalis* (Goeze, 1782) Moquin-Tandon, 1860; *Eustrongylus gigas* (Rud., 1802) Diesing, 1851; *Eustrongylus visceralis* (Gmelin, 1790) Railliet, 1885.

This giant nematode, the largest known to science, was first described from the kidney of the dog by Goeze in 1782, and has been recorded from the body cavity or the kidney of several ichthyophagous mammals, including the dog, wolf, puma, glutton, raccoon, coati, martin, skunk, mink, otter, seal, ox, and horse. It has been reported from Europe, North and South America, and has been obtained once in China (Nanking). It has been found as a human parasite more than 9 times (Brumpt). The worm is reddish in color, cylindrical in shape, slightly attenuated at both ends and measures 14 to 20 cm. in length by 4 to 6 mm. in diameter for male specimens (Fig. 232 *A*) and 20 to 100 cm. in length by 5 to 12 mm. in diameter for females. Along the lateral line of each side there is a series of punctate papillæ. The hexagonal mouth (Fig. 232 *B*) is provided with two series of well-developed nodular papillæ, six in each series, two pairs of which correspond with the commencement of the two lateral lines. Surrounding the caudal extremity of the male worm is a bursal cup (Fig. 232 *C*), the margin of which, as well as the inner depth, is provided with very minute papillæ. The cloacal opening is near the center of the bursal pocket. The single setiform copulatory spicule measures 5 to 6 mm. in length. The vulva of the female is situated 5 to 7 cm. from the anterior end of the worm. The eggs (Fig. 232 *D, E*) are ellipsoidal, brownish-yellow in color and have a thick shell with sculptured depressions on all parts of the surface except the poles. They measure 64 to 68 μ in length by 40 to 44 μ in transverse diameter. According to the observations of Balbiani (1870) the eggs begin to segment at the time of oviposition. Complete development of the larvæ *in ovo* requires six months or less, depending on the season. The eggs are extremely resistant to external conditions and may remain viable for five years or more.

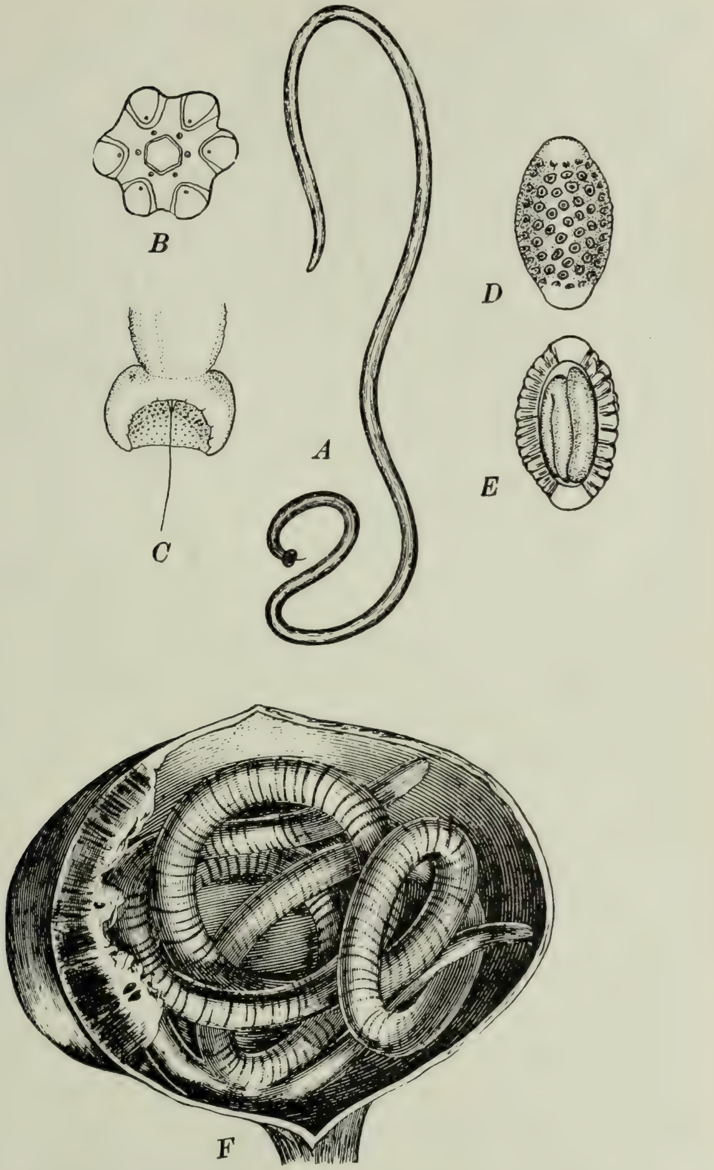

FIG. 232.—*Dioctophyme renale.* *A*, adult male worm, three-eighths natural size (after Railliet, Traité de Zoöl. Med. et Agr. Courtesy of Vigot Frères, Paris); *B*, head end of worm showing papillæ, × 7 (after Stefanski); *C*, ventral view of bursa of male, showing papillæ on inner surface, × 7 (after Stefanski); *D*, *E*, immature and embryonated eggs, × 300 (original); *F*, worm coiled in pelvis of kidney, from which most of the parenchyma has been digested, three-fourths natural size. (After Railliet, Traité de Zoöl. Med. et Agr. Courtesy of Vigot Frères, Paris.)

The first stage larva is fusiform, measuring about 240 by 14 μ. In the anterior part of its esophagus there is a three-toothed onchium. The life cycle lacks complete elucidation but Ciurea (1921), following Leuckart's clue, has been able to infect one of a litter of four puppies by feeding raw fish (*Idus idus*) containing encysted mature larvæ.

Pathogenicity and Symptomatology.—The adult worms live in the pelvis of the kidney or in the body cavity. One or more worms may be present at one time, the largest number recorded being eight from the kidney of a wolf. In the kidney they little by little consume the renal parenchyma (Fig. 232 *F*), finally leaving only the enveloping tunica. The urine in these cases contains blood and pus. Renal colic and other direct symptoms result during the early stages, while in late cases dysfunction of the infected organ is complete. In infected dogs several types of nervous disorders have been ascribed to the presence of the worms, including rabid symptoms. The worms may attempt to escape down the ureter and produce acute uremic poisoning or may succeed in escaping from the urethra. The authenticated human cases have all been renal infections but the worm has been recovered from the abdominal and thoracic cavities and from the liver of dogs.

Diagnosis.—In renal infections where a female worm is present the discovery of the typical eggs is diagnostic.

Prognosis.—Very grave.

Therapeusis.—The only known method of removing the worm is by operation.

Prophylaxis.—Thorough cooking of fresh-water fish, if the latter is actually the normal intermediate host, will remove the possibility of individual danger.

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CHAPTER XXVIII.

MYOSYRINGATE NEMATODES (CONCLUDED).

SUPERFAMILY FILARIOIDEA (WEINLAND, 1858) STILES, 1907.

(FILARIOID FORMS.)

THIS superfamily comprises those spirurate nematodes of filiform outline, having a simplified anterior end, without conspicuous oral labia. The buccal vestibule is lacking or inconspicuous. The esophagus is cylindrical, without a cardiac bulbus, with or without differentiation into two parts. The mid-intestine is simple and may be atrophied posteriorly. In some species the male worms possess caudal alæ; in others these are lacking. The copulatory spicules are commonly unequal and dissimilar. The vulva of the female worms is preëquatorial, usually in the esophageal region. The species of this group have become adapted to a habitat in the deeper tissues of the vertebrate body, including the circulatory, lymphatic, muscular, and connective-tissue layers, or the serous cavities. An insect intermediate host is required. Filarioid species are classified under two families, **Filariidæ** (Cobbold, 1864) and **Fuelleborniidæ** nov. nom. (= **Dracunculidæ** Leiper, 1912), both of which contain species parasitic in man.

Family FILARIIDÆ (Cobbold, 1864) Claus, 1885.

In this family the females are not more than three or four times as long as the males. The anal opening is constantly present in both males and females. The cuticula is usually smooth, but may be characterized by transverse striations, annular thickenings or bossing. Of the eight or more subfamilies, four (**Filariinæ** Stiles, 1907; **Onchocercinæ** Leiper, 1911; **Loainæ** Yorke and Maplestone, 1926, and **Setariinæ** Yorke and Maplestone, 1926) contain human parasites.

Subfamily Filariinæ Stiles, 1907.—In these species the cuticula is either smooth or striated. The mouth may possess two insignificant lateral lips or lack such structures, but is not bounded by chitinous peribuccal rings or epaulette-like ornamentation. The copulatory spicules of the male are unequal and dissimilar. Certain larval stages of species with known life histories are passed in mosquitoes. The human representatives of this subfamily are *Wuchereria bancrofti* (Cobbold, 1877) and *Dirofilaria magalhæsi* (Blanchard, 1895).

GENUS WUCHERERIA DA SILVA ARAUJO, 1877.
(genus named for Dr. O. Wucherer).

36. **Wuchereria bancrofti** (Cobbold, 1877) Seurat, 1921.

Synonyms.—*Filaria sanguinis hominis* of Bush, 1872; *Filaria sanguinis hominis ægyptiaca* Sonsino, 1874; *Filaria bancrofti* Cobbold, 1877; *Wuchereria filaria* da Silva Araujo, 1877; *Filaria wuchereri* da Silva Araujo, 1878; *Filaria sanguinis* v. Beneden, 1878; *Filaria nocturna* Manson, 1891; *Filaria philippinensis* Ashburn and Craig, 1906.

Historical.—The pathological picture produced by Bancroft's filaria, consisting of elephantiasis of the leg and scrotum and, to a certain extent, lymph scrotum, was undoubtedly described by ancient Hindu savants, as well as by Rhazes, Avicenna and other Arabian physicians, although the disease (*elephantiasis arabicum*) was confused with leprosy (*elephantiasis græcorum*) as well as Madura foot. Hematochyluria was first described by Chapotin in 1812. Meanwhile many workers in Brazil (1800–1854) had been studying the various clinical expressions of the infection. In 1863 Demarquay in Paris first demonstrated microfilariæ in hydrocele fluid of a patient from Havana and in 1866 Wucherer made a similar discovery in chylous urine of a Brazilian patient (first published in 1868). In 1872 Lewis in India published his discovery of the same organism in the peripheral blood of a Hindu. In 1874 Sonsino published a memoir in which he described microfilariæ in the blood and urine of a Jewish lad in Egypt. The first adult worms (five in number, all females) were recovered by the elder Bancroft of Brisbane, Australia (1876–1877), who had seen the larvæ the previous year in a case of chyluria. These adults were studied and described by Cobbold (1877) under the name *Filaria bancrofti.* The first males were apparently described by Bourne in 1888 from material received from Sibthorpe. Meanwhile Manson of Amoy, China, first corroborated Lewis in furnishing evidence of the etiological relationship between microfilariæ in the blood and urine on the one hand and elephantiasis and lymph scrotum on the other (1875), and later 1877) showed that in certain cases the larvæ might be present in the blood without concomitant symptoms. Manson's further studies on the infection (1878–1882) contributed two very important discoveries,—the first (1878) being an experimental proof that *Culex "fatigans"* was not only a transmitter of the larval form of the worm from man to man but was actually an intermediate host in which the larvæ underwent a profound metamorphosis; the second (1879) consisting in a demonstration of the nocturnal swarming (periodicity) of the microfilariæ in the peripheral circulation and diurnal concentration in the pulmonary vessels. The mosquito transmission was confirmed by Lewis and by da Silva Araujo a few months after Manson's original discovery.

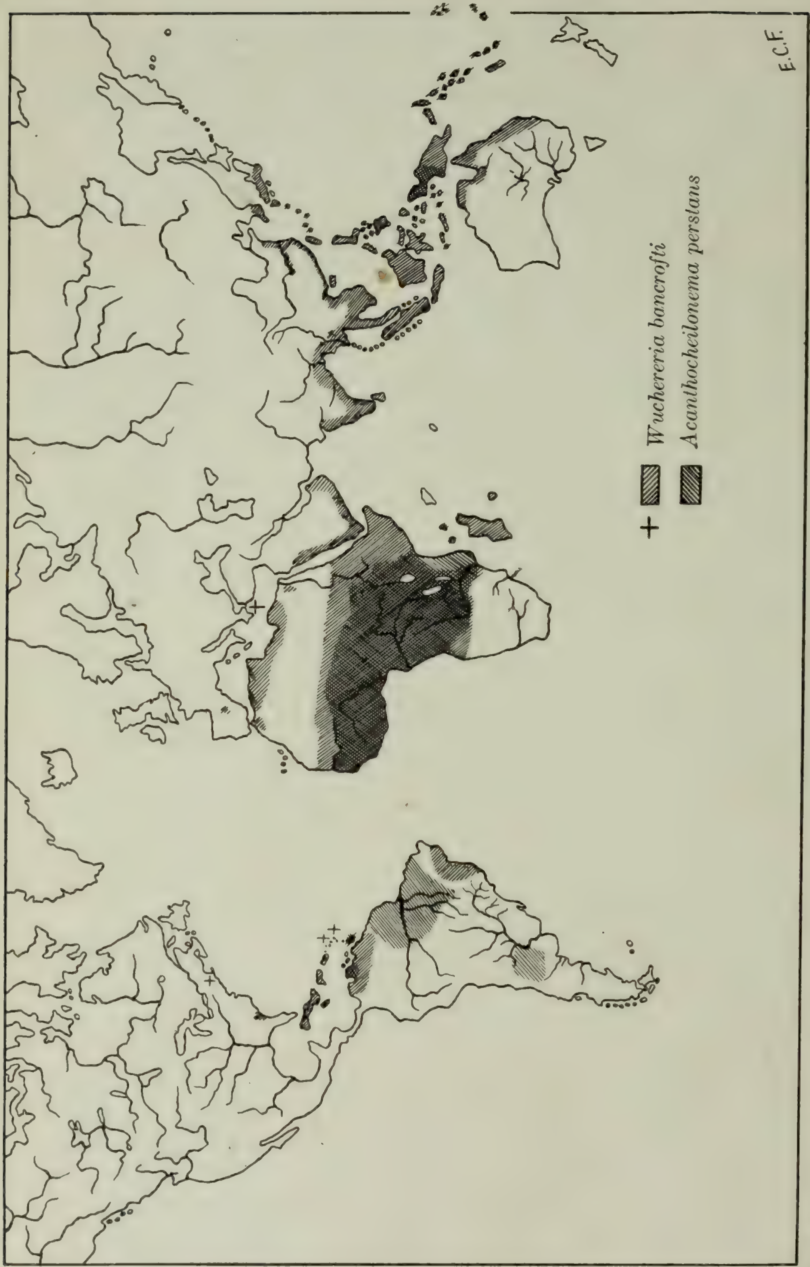


FIG. 233.—Map showing the distribution of *Wuchereria bancrofti* and *Acanthocheilonema perstans.* (Compiled from various sources.)

The more recent studies on Bancrofti's filaria have been primarily epidemiological and pathological, the most important of which have been those of Bahr (1912) in Fiji and O'Conner (1923) in Ellice, Tokelau and Samoa. These investigators have found little or no periodicity in Polynesian microfilariæ morphologically indistinguishable from those of *W. bancrofti* harbored by cases having typical clinical symptoms.

Geographical Distribution of Bancroft's Filaria.—In general it may be stated that *Wuchereria bancrofti* occurs indigenously throughout the world from about 41° north to about 28° south latitude in the Eastern Hemisphere and from about 30° north to about 30° south latitude in the Western Hemisphere. (See map, Fig. 233.) It is believed that the infection originated in Southern Asia, from which it spread, on the one hand, through Malaya to Micronesia, Polynesia and Australia and through India to Southern and Central China and Japan; and on the other hand, through Africa to the Americas. In Asia it is found along the whole of the southern coast from Arabia through India, the Malay States, French Indo-China, Southern and Central China up to Southern Shantung Province, China, and *via* the coastal islands of the China Sea to Southern Korea and the southern half of Japan. It is found in Sumatra and Java, in Borneo, Celibes, the Philippines, New Guinea and Papua, and from Port Darwin in the Northern Territory, Australia, along the coast eastward and southward through Queensland to the northern part of New South Wales. It is extremely common in Fiji, Samoa, in the Gilbert and Ellice Islands and other parts of Polynesia. In Africa it is frequently encountered along the East Coast from Eritria to the mouth of the Zambesi and on the neighboring islands of Madagascar, Mauritius and Reunion. In North Africa it has a coastal distribution from Lower Egypt to Morocco. In Central Africa the infection is contiguous with the disease on the East Coast and extends through in the same broad belt to the West Coast. In Europe it has been reported as indigenous only in Barcelona and in Turkey. In the United States only one area, that around Charleston, South Carolina, has been discovered. It is of common occurrence among the peoples of the Carribbean, including Cuba and Porto Rico. It occurs in Colombia, Venezuela, the Guianas, in Bahia (Brazil) and possibly in Peru. Some of these records possibly refer to *Acanthocheilonema perstans,* which, in the central belt of Africa and in Western New Guinea, occurs in conjunction with *Wuchereria bancrofti.*

Morphology and Life Cycle of the Parasite.—*The Adult Worm.*—The adult specimens of *Wuchereria bancrofti* are creamy-white filiform worms, with smooth cuticula and a cylindrical shape; they gradually taper toward both ends, which terminate bluntly. The head (Fig. 234 *A*) is slightly swollen and is provided with two rows

of small sessile papillæ. The mouth is unarmed and there is no buccal vestibule. The oral aperture leads directly into a cylindrical esophagus of moderate length, divided into an anterior muscular part and a posterior glandular portion. The mid-intestine is a tube

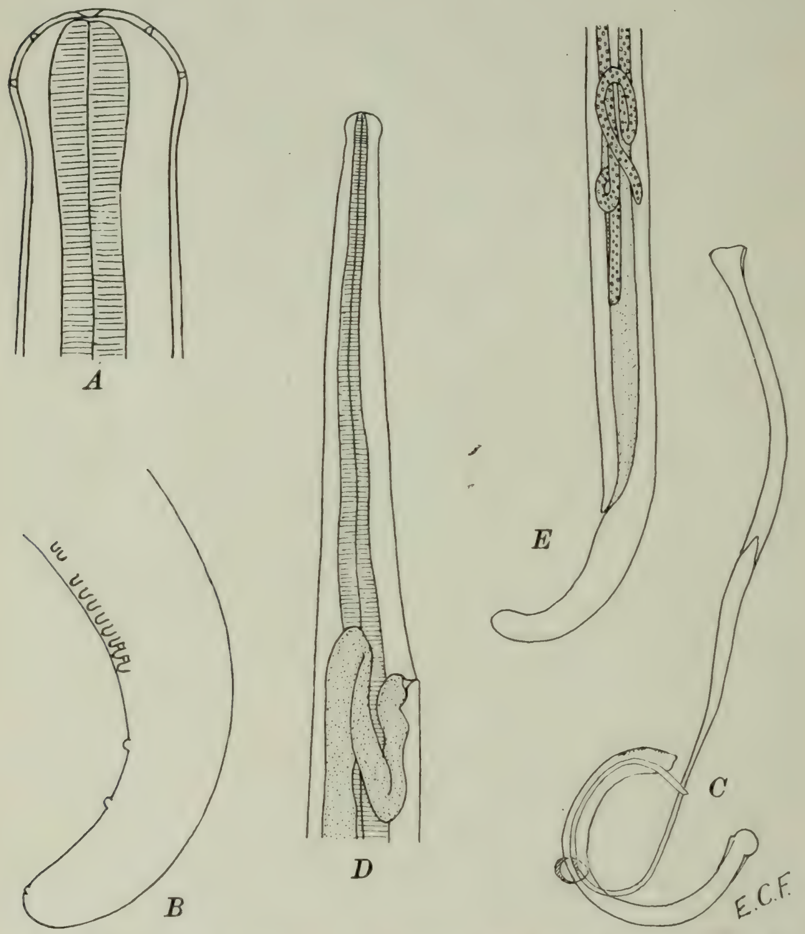


FIG. 234.—*Wuchereria bancrofti.* *A*, anterior end, ventral view, showing the cephalic papillæ, × 400; *B*, posterior end of male, with papillæ; *C*, spicules and gubernaculum of male worm; *D*, anterior end of female, lateral view, × 90; *E*, posterior end of female, lateral view, × 90. (*A*, *D*, *E*, after Yorke and Maplestone, Nematode Parasites of Vertebrates; *B*, *C*, after Leiper, Trans. Royal Soc. of Med. and Hyg.)

of one-third to one-fifth the diameter of the body of the worm. and opens into a short rectum in the plane where the worm begins to narrow posteriorly. The male measures about 40 mm. in length by 0.1 mm. in cross-section. The caudal extremity (Fig. 234 *B*)

is curved sharply ventrad, at times through an angle of 360 degrees. According to Leiper (1913) there are 12 pairs of sessile circumoral papillæ of which 8 pairs are preanal and 4 immediately postanal in position. Further caudad there are 2 pairs of rather large sessile papillæ, and at the caudal extremity a solitary pair of minute size. The present author has been able to verify Leiper's description from material secured from Central China. There are no caudal alæ. There are two copulatory spicules (Fig. 234 *C*) of unequal length (0.2 mm. and 0.6 mm. respectively), the longer one being cylindrical and tapering distally to a long lash with delicate alæ and ending in a spoon-like termination, the shorter one being trough-shaped, having a uniform thickness, and being provided with coarse markings near its distal end. The gubernaculum is crescent-shaped. The female measures from 80 to 100 mm. in length by 0.24 to 0.3 mm. in cross-section. The vulva (Fig. 234 *D*) opens about 0.8 to 0.9 mm. behind the anterior extremity of the body. The swollen vagina is about 0.25 mm. long and leads into a uterus which shortly divides into two branches. These tubules coil back and forth through the greater extent of the body, their diameter being about three times that of the mid-intestine. The two ovaries and associated ducts extend to within 1 mm. of the caudal extremity (Fig. 234 *E*).

The embryos in the inner portion of the uteri are coiled within a transparent oval membrane which measures about 38 by 25 μ. As they become crowded more and more toward the outer portion of the uteri the membranes elongate to form a "sheath" encasing the microfilariæ but somewhat longer than the enclosed organisms, so as to allow room for the microfilariæ to slip back and forth within the "sheath." It is in this form that the larvæ ordinarily escape from the parent worms. Usually described as viviparous, this condition is actually one of oviparity since the membranes surrounding the larvæ are the original egg capsules laid down by the parent and not cuticular sheaths secreted by the larvæ themselves. The adult worms live normally in the lymphatics and the lymph glands; the microfilariæ on escaping from the gravid females may either remain in the lymph or migrate through the lymph capillaries into the blood stream. In case female worms are injured the larvæ may be discharged in the immature oval condition, under which circumstances they are too broad to pass the lymph capillaries. Manson attached considerable importance to this phenomenon as an explanation for the obstruction of the lymphatics frequently associated with the infection.

The larvæ of *Wuchereria bancrofti* (Fig. 235), which are recovered from the peripheral blood or the lymph current, or are discharged in chylous urine, are minute serpentine organisms, measuring 127 to 320 μ in length by 7.5 to 10 μ in diameter. Those in the lymph stream are usually considerably shorter and slightly thicker than

the ones that have escaped into the circulation or urinary tract. They are bluntly rounded at the anterior end and attenuate posteriorly. The cuticula is usually described as having delicate transverse striations but these are probably artefacts due to fixation. They move about gracefully in a blood-film, pushing the blood corpuscles to one side. In living worms the oral end is being constantly covered and uncovered by a prepuce; it is also provided with a delicate stylet which may be introverted or everted as occasion requires. The inner structure of the larva cannot be clearly seen without the aid of staining. (For methods of staining see

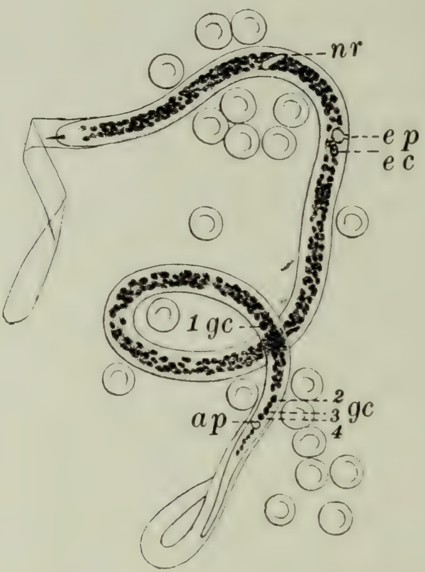


FIG. 235.—Ensheathed microfilaria of *W. bancrofti*, with oral stylet. *nr*, nerve ring; *ep*, excretory pore; *ec*, excretory cell; *1, 2, 3, 4, gc*, genital cells; *ap*, anal pore. × 666. (Original.)

Chapter XXXII, pp. 502–503.) With either vital dyes or permanent stains the central axis of the microfilaria will be found to be composed of a column of deeply-staining nuclei but certain landmarks can be found. These consist of the nerve ring (*nr*) in the anterior portion of the worm, an excretory pore (*ep*) and an adjacent excretory cell (*ec*) a short distance behind the nerve ring, genital cells (*1-gc, 2-4-gc*) in the posterior part of the organism, the latter three cells being situated close together in front of the anal pore (*ap*). The relative distances of these landmarks from one another along the longitudinal axis, together with the size and relation of length to breadth, are utilized in specific diagnosis of the larva, since they

are constant in the same species. Thus in this species the relative percentage distance of these locations from the anterior extremity, according to Fülleborn and Rodenwaldt, is: nerve ring, 20; excretory pore, 29.6; excretory cell, 30.6; genital cell *1*, 70.6; anal pore, 82.4; with genital cells *2*, *3* and *4* situated immediately in front of the anal pore. Likewise the terminal 5 per cent of this larval stage of *W. bancrofti* is free from nuclei. This latter important character makes it easy to distinguish it from the similar stage of *Loa loa*, in which the nuclei extend to the caudal extremity.

Filarial Periodicity.—In 1877 Manson first found in his China cases showing microfilariæ, that the maximum concentration of these larvæ in the peripheral blood occurred at night. This observation of the nocturnal periodicity of larvæ of this species has been observed consistently since that time in autochthonous infections in China, India, Australia and the West Indies. The maximum concentration in the peripheral circulation is normally between 10 P.M. and 2 A.M., while in the daytime Manson found the embryos concentrated in the pulmonary vessels, the capillaries of the heart muscles and the Malpighian tufts of the kidneys. On the other hand autochthonous cases in the Philippines, Fiji, Samoa, Tokelau, Wallis, the Ellice Islands and Tahiti, which have an infection consisting of adults and microfilariæ morphologically indistinguishable from the Asiatic, Australian and West Indies strains and which are considered to be the same species, lack specific periodicity (*i. e.*, are non-periodic). The theories that have been advanced to explain this phenomenon are primarily based on mechanical, chemical or biological processes. It was first supposed that the period of sleep and the relaxation of the capillaries at night or contraction during the daytime were responsible for the condition, but this theory fails to explain non-periodicity. The increase in flow of chyle at night, carrying the embryos with it into the blood stream, is subject to the same criticism. Chemotactic responses to oxygen and carbon dioxide gases have also been advanced as an explanation without any considerable valid evidence. The theory of adaptation to the life of the insect host was first suggested by Manson; this theory is believed to have met with substantial confirmation in the hands of Manson-Bahr in Fiji, who concluded that where the mosquito host is a night-feeding species, as, for example, *Culex fatigans*, the microfilariæ definitely manifest a nocturnal periodicity, whereas non-periodicity occurs where a day-feeding mosquito, such as species of *Aëdes*, is utilized. It is argued, however, that these observations are entirely too isolated and without confirmation in other endemic areas to explain satisfactorily the intermediate host-parasite relationship of this species on the basis of adaptation alone. The following observations have a bearing on one or another of the theories proposed. In persons sleeping during the daytime the micro-

filariæ have a diurnal periodicity, although Yorke and Blacklock found that it required eleven days for a complete reversal in periodicity in a person changing from nocturnal to diurnal sleep. Persons harboring a strain manifesting nocturnal periodicity may move their residence to a country where only the non-periodic strain is endemic without causing a modification of the periodicity. In Australia various observers have found that during the winter months when *Culex fatigans* disappears, there is not only a marked decrease in the percentage of cases in whose peripheral blood the microfilariæ occur, but there is a distinct diminution in the actual number of microfilariæ found in films of peripheral blood of positive cases. Altogether the evidence for one or the other of these theories is still unsatisfactory and unconvincing, and further intensive investigations on both the periodic and non-periodic strains of the organism are needed in order to throw light upon this perplexing question.

The microfilariæ, once set free by the parent worm into the circulation, are able to live for a considerable length of time which has not been definitely determined.

The Mosquito Intermediate Host.—In 1878 Manson demonstrated that *Culex "fatigans"* served as a "nurse" for the microfilariæ of the China strain of *Wuchereria bancrofti.* In the appropriate mosquito the microfilariæ pass into the stomach along with the blood meal. Here they become "exsheathed" in an hour or two. Some of them pass out with the feces, but others invade the stomach wall and in the course of twenty-four hours migrate into the thoracic muscles, where their movement becomes greatly reduced. In the next two days the larva becomes rapidly modified into a sausage-shaped organism, measuring 150 μ in length by 10 μ in diameter. Multiplication of the nuclei of the intestinal tract proceeds rapidly and the tail is reduced to a stump. Between the third and the seventh days the internal organization becomes more definite (Figs. 236 and 237, *A*), so that an esophagus consisting of an anterior muscular portions (*ae*) and a posterior glandular part (*pe*) become differentiated; intestine (*i*) rectum (*r*) and anal opening (*a*) are distinct; and the digestive tract as a whole becomes separated from the somatic layers by an intervening body cavity. The genital primordium (*gc* probably *1gc* of Fig. 235) is still undeveloped. The larva now measures 225 to 300 μ in length by 15 to 30 μ in cross-section. Three subterminal caudal papillæ now appear. During the beginning of the second week the second moult (*i. e.*, the moult of the first true sheath) takes place. The worm now rapidly elongates until it reaches a length of 1.4 to 1.5 mm. Active movement is resumed and the parasite migrates from the thoracic muscles into the head, where it lies coiled up (Fig. 237 *B*), ready to enter the proboscis sheath (*e. g.*, the labium). The complete period of devel-

opment in the mosquito varies from ten days to six weeks or more, depending primarily on the temperature and moisture, but also, perhaps, on the species of mosquito. When the infected mosquito begins to bite another mammal, following the maturity of the metamorphosed microfilariæ, the larvæ, attracted by the warmth of the skin, migrate down the labium, and emerge through the terminal portion, usually in pairs, near the site of the proboscis puncture

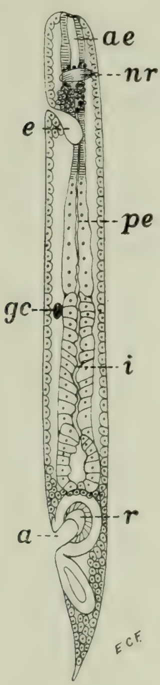
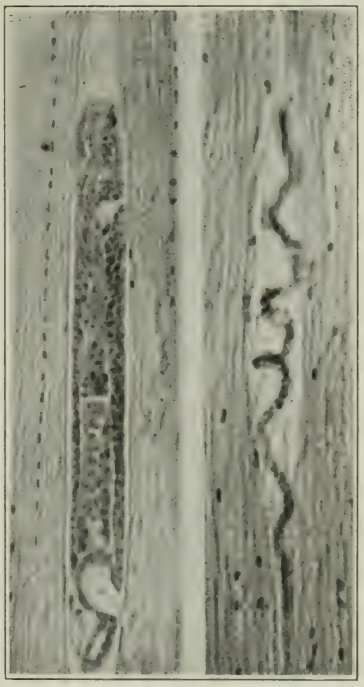


Fig. 236



A Fig. 237 *B*

Fig. 236.—Sausage-shaped larva of *W. bancrofti* from thoracic muscles of *Culex pipiens*. *ae*, anterior esophagus; *nr*, nerve ring; *e*, excretory bladder; *pe*, posterior esophagus; *gc*, genital primordium; *i*, mid-intestine; *r*, rectum; *a*, anus. × 300. (Original.)

Fig. 237.—*A*, Photomicrograph of sausage-shaped larva of *W. bancrofti* in *Culex pipiens; B*, photomicrograph of mature larva in *Culex pipiens*. (Photographs by Dr. C. U. Lee.)

(Fig. 238). According to Fülleborn, who studied the subsequent behavior of the microfilariæ of *Dirofilaria immitis*, the larvæ do not enter the puncture wound but invade the superficial layers of the skin on their own behalf, a portion of the larvæ successfully penetrating through to the peripheral blood capillaries.

Complete development of the larval *Wuchereri bancrofti* has been observed in the following mosquitoes:

1. *Culex fatigans.* China, India, Egypt, Australia, West Indies, Antilles, Trinidad, Philippines, Pacific Islands, St. Lucia, and Charleston, S. Carolina.
2. *Culex pipens.* Central China.
3. *Aëdes œgypti.* West Africa, New South Wales.
4. *Aëdes variegatus* (*Stegomyia scutellaris*). Pacific Islands.
5. *Aëdes* (*Finlaya*) *togoi.* Japan.
6. *Mansonia* (*Mansonioides*) *pseudotitillans.* Malaysia.

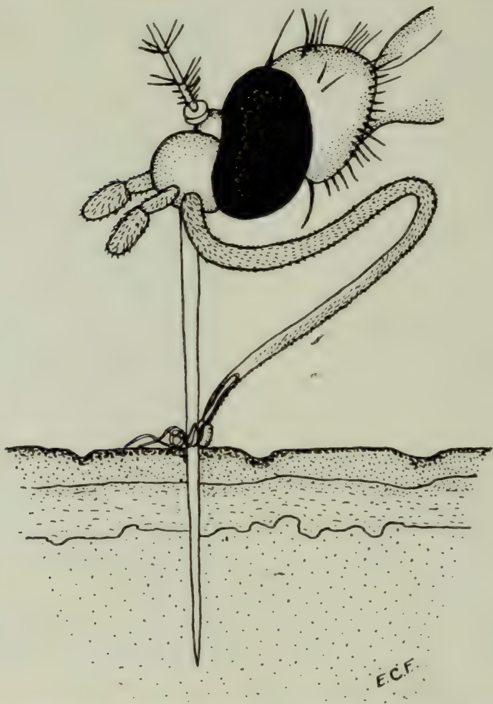


FIG. 238—Diagram of a female mosquito discharging mature filarial larvæ while securing a blood meal. The stylet apparatus, consisting of *labrum-epipharynx-hypopharynx*, pierces the skin, while the proboscis-sheath (*labium*, with terminal *labellæ*) buckles backward, without penetrating the opening. The microfilariæ escape from the inner membrane of the sheath and crawl out upon the surface of the skin, which they actively penetrate in the vicinity of the wound. (Original.)

7. *Mansonia* (*Mansonioides*) *uniformis* (seu *africanus*). Central Africa.
8. *Anopheles* (*Nyssorhynchus*) *albimanus.* Caribbean.
9. *Anopheles* (*Myzomyia*) *rossi.* India.
10. *Anopheles* (*Myzomia*) *costalis.* West Africa.
11. *Anopheles* (*Anopheles*) *algeriensis.* Tunis.
12. *Anopheles* (*Myzorhynchus*) *nigerrimus.* Travancore.

About 22 other Culicidæ have been listed in which development

is aborted or incomplete. (See pp. 547–549). Of *Aëdes ægypti,* Edwards states that the almost universal association of this species with *Culex fatigans,* together with the diurnal feeding habits of the former species, would render it less liable to infection and less able to develop a fixed relationship with the worms than the latter species in case the larvæ have a definite nocturnal periodicity.

Manson-Bahr found that when fewer than one microfilaria were present in 2 c.mm. of the patient's blood, the appropriate mosquito frequently failed to acquire an infection; that when there were ten or more larvæ per c.mm. the infection tended to kill the mosquito, and that when fed on blood containing about three larvæ per c.mm. the optimum development took place in *Aëdes variegatus.*

The mature larvæ which emerge from the mosquito, on penetrating through the skin, reach the peripheral bloodvessels, travel through the body until they reach the lymphatics, where they grow to sexual maturity, mate, and in due course produce the microfilarial offspring. Man is the only known host of the adult worms.

The Site of the Adult Worms.—The male and female worms live together, often coiled into inextricable tangles. They may be located in nodular dilatations of the distal lymphatics or may lie more loosely in lymphatic varices; or they may at times be present in the lymphatic trunks between the glands, in the glands themselves, or even in the thoracic duct.

Pathogenicity and Symptomatology.—In the majority of cases *Wuchereria bancrofti* infection produces no manifest lesions or apparent symptoms. The only evidence of the infection is the presence of the microfilariæ in the peripheral blood. In a certain percentage of cases, however, there is indubitable proof that the worms are responsible for a diseased condition of the patient. In another group of cases there are symptoms which have been commonly referred to the worms which have been demonstrated in the tissues, but which undoubtedly involve secondary invaders. In still another series of cases similar symptoms are found but the presence of the worms cannot be demonstrated.

1. *Symptomless "Filariasis."*—This condition obtains when the adult worms are so situated in the lymphatics, that neither they nor their progeny obstruct the course of the lymph stream. Neither does their presence provoke a tissue reaction in the immediate vicinity. The existence of the infection is usually discovered only by accident or in surveys of the population when blood-films are examined. Such an infection may be regarded as a perfect adjustment between parasite and host. The worms probably live for years, continuously discharging a swarm of microfilariæ into the blood stream. Nevertheless the host is a carrier and is in some respects more dangerous to the community than an infected individual showing symptoms.

2. *"Filarial" Disease Caused by Wuchereria Bancrofti.*—Probably the commonest effect of *Wuchereria bancrofti* in the lymphatics is mechanical obstruction of lymph flow, giving rise to varix lymphaticus. In case of blockage of the thoracic duct the lymphatics of the abdomen, pelvis, groin or scrotum may be enormously distended by chyle forced to find collateral tracts in order to enter the general circulation. If the integument of the scrotum is involved, "lymph scrotum" results; if the groin is involved, "varicose groin-glands" develop; if the lymphatics of the bladder or kidneys are affected and the tension becomes too great, rupture of the vessels results in

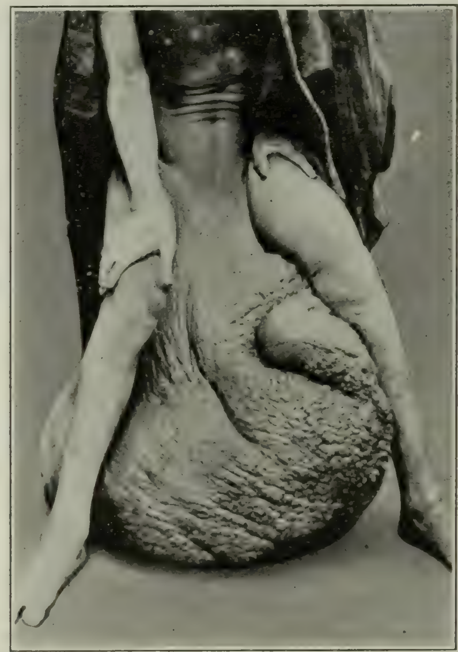


FIG. 239.—Elephantiasis of the scrotum in filariasis bancrofti, in a Japanese subject. (From "Medicina Bildaro Fotografa," Elefantiazo kaj Filariazo.)

chyluria. Similar distention and rupture in the tunica vaginalis may give rise to "chylocele," and of the peritoneum, to chylous ascites. Similar obstructions of other parts of the lymphatics occasion comparable pictures. In such cases microfilariæ can usually be demonstrated in the blood as well as in the chylous fluid.

In a large proportion of cases with varix lymphaticus there is an accompanying or subsequent elephantiasis (elephantiasis arabum). However this condition is not produced by mere lymph stasis. It is due to other factors, producing fibrosis and hypertrophy of the tissues in and around the lymph tracts and glands. In 95 per cent

of the cases the parts affected are in the lower extremities and the scrotum (Fig. 239). In women the vulva commonly and mammary glands rarely are said to be the seat of enlargement. The changes produced in the immediate vicinity of the parasite or in the more distal portions of the afferent vessels consist primarily in focal fibrosis and necrosis (Fig. 240) and at times of giant-cell formation. Whether this change in the host tissue is caused by toxic secretions of the worms or by the products of disintegration of the microfilariæ or of the adult worm, is not clear. In uncomplicated cases, however, the affected parts are bacteria-free. Abscess-formation may result from irritation produced by dead worms. Microfilariæ

FIG. 240.—Section through a lymph node with *Wuchereria bancrofti* in a pocket of fibro-connective tissue. × 66. (Original photomicrograph from a preparation by Mr. Conrad Bauer.)

are much less frequently found in the blood in complications of elephantiasis than in varix lymphaticus.

3. *"Filarial" Disease with Complications Produced by Secondary Invaders.*—A considerable number of cases of lymph varix and elephantiasis manifests symptoms of lymphangitis of the various parts of the lymphatics. (See Fig. 241.) The condition may be localized or may become generalized. It is usually attended with "elephantoid fever," a pyrexia of recurrent type, with rigor and terminal diaphoresis, commonly confused with malarial fever. Dermatitis and cellulitis may develop, particularly in the elephantoid tissues. Workers in British Guiana have demonstrated the

presence of staphylococci or streptococci in cases with inflammatory complications of the lymphatics. Anderson (1924) believes that the damage produced by the filarial worms in the intima of the vessels prepares the way for invasion of the bacteria, which may have been responsible for the changes produced long after the adult worms have died and the microfilariæ have disappeared from the circulation.

FIG. 241.—Elephantiasis in a Hindu girl in British Guiana; filariasis bancrofti with probable septic complications. (After Sambon, Journal of Tropical Medicine and Hygiene.)

4. *Lymph Varix and Elephantiasis Not of Filarial Origin.*—These diseased conditions, without inflammatory complications, occur in certain areas where *Wuchereria bancrofti* is not known to occur, and under such circumstances must be attributed to a lymph stasis produced by an unknown cause. Where lymphangitis is an accompaniment it is probably of secondary septic origin.

For detailed descriptions of the various complications of filarial infection special treatises should be consulted.

Diagnosis.—Infection with *Wuchereria bancrofti* can be demonstrated in a high proportion of infected individuals from blood films or from chylous exudate of lymph varices. A higher percentage of positive findings can be obtained in early uncomplicated cases than in late cases, particularly those with sepsis. In regions where the organism manifests nocturnal periodicity, blood for examination should be obtained between 10 P.M. and 2 A.M. A certain proportion of cases with filarial infection as a primary cause cannot be definitely diagnosed by laboratory methods.

Therapeusis.—There is no known drug which is specific for *Wuchereria bancrofti*. Various operative procedures have been advocated. In some cases obstruction of lymph flow may be removed and elephantoid tissue wholly or partially excised. In other instances deep lymph drainage has been practised. In septic complications vaccine therapy is helpful.

Prophylaxis.—No satisfactory program has been developed for the reduction or eradication of *Wuchereria bancrofti* infection in endemic areas. Such a plan must include both anti-mosquito measures and a consideration of the danger of carriers of the infection.

Genus Dirofilaria Railliet and Henry, 1911.
(genus from *dirus*, cruel, and *filaria*).

37. **Dirofilaria magalhãesi** (Blanchard, 1896 *nec* 1895), Railliet and Henry, 1911.

Synonyms.—*Filaria magalhæsi* Blanchard, 1896; *Filaria Bancrofti* Magalhães, 1892.

The members of the genus *Dirofilaria* are characterized by the absence of oral labia and by possessing very inconspicuous cephalic papillæ. The esophagus is relatively short and is divided into an anterior muscular and a posterior glandular portion. The spirally-coiled posterior extremity of the male worm has a bluntly conical termination and is provided with caudal alæ. There are large pedunculated preanal and small postanal papillæ, the spicules are unequal, and a gubernaculum is wanting. The vulva of the female worm is slightly post-esophageal in position. The larvæ hatch before they escape from the mother worms and the "unsheathed" microfilariæ circulate in the blood. These species live in the chambers of the heart and connective tissue of various mammals. The most common species is *Dirofilaria immitis* (Leidy, 1856), which lives in the right heart of dogs. The only species found in man is *D. magalhæsi*, which has been reported once from the left ventricle of a Brazilian child (de Magalhães, 1887).

One male and one female worm were recovered from the infection. The male measures 83 mm. long by 0.407 mm. in diameter. The tail is coiled 540 degrees. There are 4 pairs of pedunculated promi-

nences, and 4 pairs of postanal papillæ, all of which were described as "mulberry-shaped," with superficial denticulations. Of the two unequal spicules the lesser has a length of 230 μ. The cloacal opening is situated 0.11 mm. from the posterior extremity. The female measures 155 mm. in length by 0.715 mm. in diameter The vulva is situated 2.56 mm. from the anterior end. The anus lies on a bilobed prominence 0.132 mm. from the rounded posterior extremity. The cuticula of the worms is opaque, white, and transversely striated.

The embryos coiled in the egg membrane *in utero* measure 38 by 14 μ. At the time of oviposition they escape from the "sheath." The length measurement of these microfilariæ is 0.3 to 0.35 mm. and the diameter 6 μ. Their cuticula is provided with delicate transverse striations. The microfilariæ circulate through the blood. Although the life cycle of the organism has not been studied it is highly probable that a mosquito serves as an intermediate host in a similar way to that described by Fülleborn for *Dirofilaria immitis*.

Subfamily 2. Onchocercinæ Leiper, 1911.—The species of this subfamily of filariid nematodes are thread-like worms, having a simple mouth without a chitinous peribuccal ring or lateral decorations. They also lack trident-like chitinous structures on either side of the anterior end of the esophagus. The cuticula has annular thickenings which are most conspicuous near the equatorial plane. There are perianal and caudal papillæ which are frequently asymmetrical, and the copulatory spicules are unequal. The vulva is situated in the esophageal region. The females are viviparous. The adult worms live in the subcutaneous and connective tissues and walls of the bloodvessels of mammals. The microfilaria, which are "unsheathed," are found in the immediate vicinity of the adult worms, in the subcutaneous tissue and in the blood stream. A biting insect, in which a metamorphosis of the larva occurs, is a required intermediate host. Of the three recognized genera of this subfamily (*Onchocerca*, *Elæophora* and *Katanga*) human infections are caused by members of the type genus.

Genus Onchocerca Diesing, 1841.

(genus from ὄγχος, hook and χερχος tail).

38. **Onchocerca volvulus** (Leuckart, 1893) Railliet and Henry, 1910.

Synonyms.—*Filaria volvulus* Leuckart, 1893; *Microfilaria nuda* Rodenwaldt, 1914.

Historical and Nosogeographical.—This worm was first described by Leuckart (1893) from specimens obtained from a native of the Gold Coast, West Africa. Since that time the infection has been

found to be relatively common along the West Coast of Africa from Sierra Leone to the Congo basin. The incidence is particularly high in the Belgian Congo, where 68 per cent of the natives in some areas are parasitized. It is also listed from East Africa (Gedoelst, 1911).

Structure and Life Cycle of the Worm.—The adult worms live in the subcutaneous or connective tissues, frequently causing the formation of tumors around themselves. When alive they are white, opalescent, very transparent nematodes, with conspicuous transverse annular thickenings of the cuticle. The body is filiform and narrowed at both extremities which are bluntly rounded. They are usually coiled and twisted into an inextricable mass. The males attain a length of 30 mm. and have a diameter of 130 μ. The caudal extremity is curved ventrad about 720 degrees (Fig. 242 *A*). There are no caudal alæ. There are usually 3 pairs of conspicuous sessile perianal papillæ (Fig. 242 *B*), and 2 or 3 pairs of minute papillæ at the caudal extremity, but the number of these papillæ is very variable and the distribution frequently asymmetrical. The two copulatory spicules are unequal in length (88 μ and 172 μ respectively) and different in structure. The females have a length measurement of 50 cm., and a transverse diameter of about 360 μ. The vulva lies in the plane slightly posterior to the esophagus (about 850 μ from the cephalic end of the worm). The vagina is directed backward. The larvæ become embryonated *in utero*, being coiled on themselves and surround by a thin oval egg membrane measuring 46 to 61 μ in length by 33 to 51 μ in breadth. According to Fülleborn they have membranous polar extensions but Blacklock (1926) makes no mention of these structures. The embryos still coiled in the egg membrane measure 264 to 290 μ by 7 to 9 μ. The larvæ on escaping from the membrane consist of two types, a large form measuring 295 to 358 μ by 6 to 9 μ and a small form measuring 221 to 287 μ by 5 to 7 μ. It seems possible that these are respectively female and male larvæ. Both types (Fig. 242 *E*) have a clear nuclei-free anterior end and a similar free posterior extremity. In addition, the region of the excretory bladder may be seen as a nuclei-free area about one-fifth the body length from the anterior end.

The studies of Blacklock (1926) have shown that in Sierra Leone the buffalo gnat, *Simulium damnosum*, is the probable intermediate host, in the thoracic muscles of which the microfilaria undergoes a metamorphosis with moult, after which the larva migrates into the head and emerges through the mouth parts from the region of the labellæ thus enabling it to infect another human being when the fly secures the next blood meal. The time for metamorphosis within the fly requires six days or more. Only man has been found naturally infected with *Onchocerca volvulus*. Experiments with monkeys have proved negative.

Pathogenicity and Symptomatology.—In certain infected areas the greater portion of the human population harbors *Onchocerca*

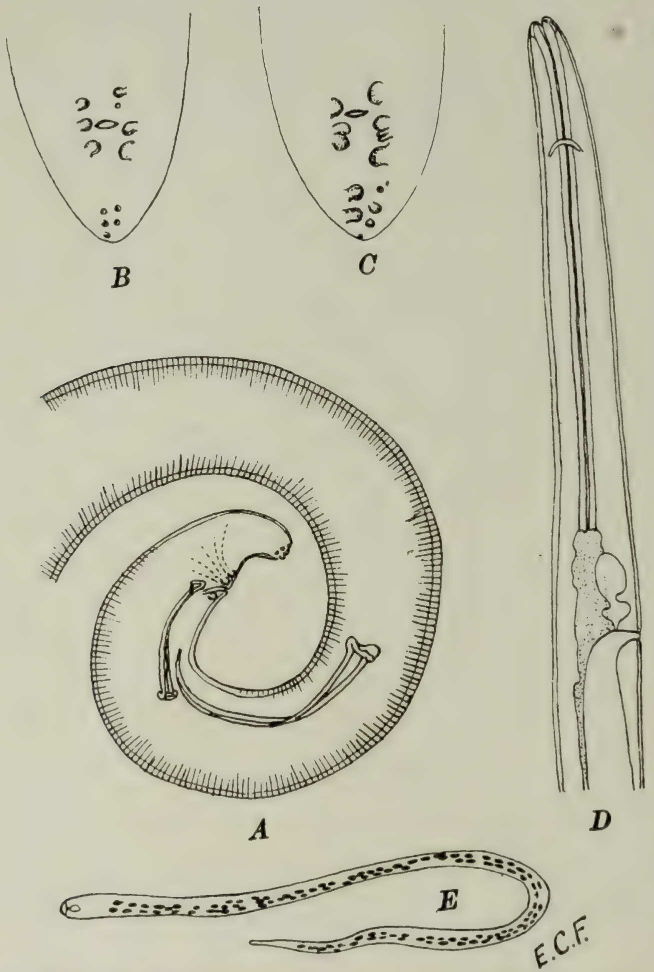


FIG. 242.—*Onchocerca volvulus* and *O. cæcutiens*. *A*, posterior end of male *O. volvulus*, lateral view, showing papillæ and copulatory spicules, × ca. 175 (after Brumpt, Précis de Parasitologie); *B*, posterior end of *O. volvulus*, ventral view, showing distribution of papillæ; *C*, similar view of *O. cæcutiens* (after Brumpt, Précis de Parasitologie); *D*, anterior end of *O. cæcutiens*, showing esophagus, anterior portion of intestine, nerve ring, and vulvar opening, × 40 (after Brumpt, Précis de Parasitologie); *E*, microfilaria of *O. volvulus*, × 300. (After Fülleborn, Handbuch des pathogen Mikroörganisms, vol. 8, courtesy of Gustav Fisher, Jena.)

volvulus. The microfilariæ can be recovered from the skin, the peripheral circulation or subcutaneous lymph channels of many of these cases which show no evidence of disease. The skin is smooth

and unmodified. On the other hand a certain proportion of cases has subdermal nodular swellings, ranging in size from a small pea to a pigeon's egg. These tumors consist of an indurated connective-tissue wall with a central cavity, in which there are usually found several adult *O. volvulus* coiled into a knot and numbers of free microfilariæ. These nodules vary from soft barely palpable to irregularly indurated masses, and are found on various parts of the body, including at times the region of the trochanter, ribs, and rarely the scalp, but most conspicuously developed in association with the joints, particularly those of the elbows (Fig. 243) and knees.

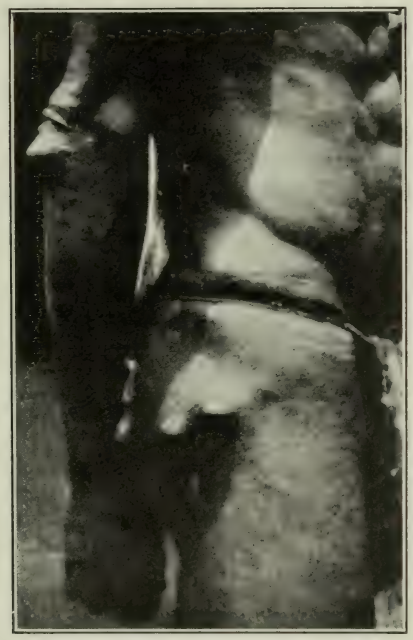


FIG. 243.—*Onchocerca volvulus* nodules in region of trochanter and at elbow. (After Blacklock, Annals of Tropical Medicine and Parasitology.)

Onchocerca volvulus tumors have never been found in the deeper layers of the body. The large indurated nodules are at times quite painful. There is no evidence of ocular defects which can be definitely attributed to this infection. The larvæ in the skin are most commonly found in the region of the loin and the thigh, which areas Blacklock has shown to be most commonly visited by feeding Simulium females. Whether "craw-craw," elephantiasis or lichenification of the skin are associated with *O. volvulus* remains to be discovered. Likewise the possibility of bacteria having a part in the production of the tumors has not been excluded.

Diagnosis.—On specific identification of the larva, which requires to be differentiated from the microfilariæ of *Wuchereria bancrofti, Loa loa, Acanthocheilonema perstans* and other possible human infections present in endemic areas; or on recovery of the adult worms.

Therapeusis.—Practically unstudied.

Prophylaxis.—This involves protection of the skin from the bites of the intermediate insect host, and anti-Simulium measures.

39. **Onchocerca cæcutiens Brumpt,** 1919.

This worm was first found by Robles (1915) in fibroma-like nodules of the scalp of about 95 per cent of the population of the Pacific slope of Guatemala between 600 and 2000 meters attitude. Fülleborn (1924) has also recorded this worm from a five-year-old boy from Mexico. The Guatemalan material was examined by Brumpt, who found the worms to be onchocercids. Although morphologically indistinguishable from *O. volvulus,* the peculiar predilection of the American type for the scalp and the face, particularly the areas around the ears, and the rarity if not complete absence of the worms and their lesions in other parts of the body, were believed by Brumpt to be sufficient warrant for designating the Guatemalan form as a new species, *O. cæcutiens.* Certain authors question the validity of this species distinction, even though the physiological differences of the American and African types are quite generally recognized. The adult males measure 24 to 42 mm. in length by 154 to 190 μ in diameter and the females, 50 cm. by 300 μ. The embryos are coiled within an egg-membrane which lacks polar attachments. The microfilariæ are "unsheathed" and are indistinguishable from those of *O. volvulus.* They can be recovered from the patient's ear-lobe as well as by venipuncture. They accumulate in immense numbers in the connective tissue of the skin. The intermediate host is unknown but species of Simulium, known locally as "coffee flies," are suspected on epidemiological grounds. No host other than man has been found to harbor the infection.

Pathogenicity and Symptomatology.—A certain proportion of cases shows no clinical symptoms, but others have painful erysipelatoid swellings of the face and scalp, and particularly of the ear-lobes. The tumefactions of the head are frequently accompanied by a marked elevation of temperature. The disease is referred to as "Coastal erysipelas." The nodules in which the adult worms are found (Fig. 244) are flattened oval or lenticular objects measuring up to 20 mm. in greatest diameter and consist of a sclerosed cortical envelope, in the center of which there is a mass of fibromucous tissue in which the worms are imbedded. Local physicians in the endemic area attribute certain ocular disturbances to the presence of the parasitized nodules in the periorbital region, but

aside from edematous swelling of the area there is no evidence of causal association of the two conditions.

Diagnosis.—On recovery of onchocercid microfilariæ from the peripheral blood or subcutaneous connective tissue or the adult worms from nodules of the scalp or face.

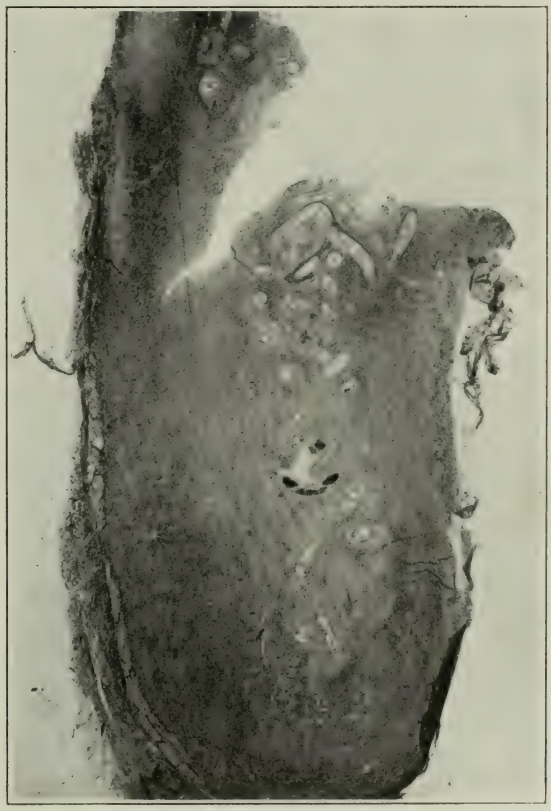


Fig. 244.—Section through nodule in *Onchocerca cæcutiens* infection, showing sclerosed outer layer, fibro-mucous matrix, and worms imbedded in matrix, × 6. (Original photomicrograph of section prepared from material presented to the author by Prof. F. Fülleborn.)

Therapeusis.—Practically unstudied. It is stated that extirpation of the nodules in the vicinity of the eyes gives prompt relief in cases with ocular complications, but this requires verification.

Prophylaxis.—Unstudied. If the "coffee fly" is the intermediate host protection of the face and scalp from bites of these gnats should afford adequate protection.

Subfamily 3. Loainæ. Yorke and Maplestone, 1926.—This subfamily consists of species in which both sexes are provided with cutic-

ular bosses; with a simple mouth lacking a chitinous peribuccal ring or lateral epaulette-like structures and without trident-like chitinous structures on either side of the anterior end of the esophagus. In some species the male worms have unequal spicules; in other species they are subequal. The vulvar opening in the female is preëquatorial, either in the esophageal region or slightly posterior to it. The eggs are embryonated when laid. The larvæ undergo a metamorphosis in Chrysops and possibly other blood-sucking flies. The adults are found in the heart-blood of birds (*Splendidofilaria*). or in the subcutaneous tissue or body cavities of mammals (*Loa, Micipsella*). One species of the type genus, *Loa loa,* is a human parasite. A closely related species, *L. papionis,* has been described by Treadgold from the baboon, *Papio cynocephalus.*

Genus Loa Stiles, 1905.

(genus from *loa,* a term commonly used by the natives of Angola, West Africa, for the worm).

40. **Loa loa** (Cobbold, 1864) Castellani and Chalmers, 1913.

Synonyms.—*Filaria medinensis* Gmelin, 1788 *pro parte; Filaria oculi humani* Dujardin, 1845; *Filaria lacrymalis* Dubini, 1850 *nec* Gurlt, 1833; *Filaria oculi* Gervais and van Beneden, 1859; *Dracunculus oculi* Diesing, 1860; *Filaria subconjunctivalis* Guyon, 1864 of Braun, 1902; *Dracunculus loa* Cobbold, 1864; *Filaria loa* Guyot, of Leuckart *et al.;* Larva: *Microfilaria diurna* Manson, 1891.

Historical and Nosogeographical.—The earliest record of the loa worm was that of Mongin (1770) who extracted a specimen from between the conjunctiva and albuginea of a negress at St. Dominigo (Hayti). There followed a series of cases described from the New World by Bajon (1777, Cayenne, F. Guiana), Arrachart (1805, St. Dominigo), Larry (1812, St. Dominigo), Roulin (1828, Magdalena R., Colombia), Guyon (1838, Martinique), Lallemant (1844, Rio de Janeiro), and others. All of these cases were recently imported West African slaves. The first authentic observations of the presence of the species in indigenous territory were those of Guyot (*ca.* 1777) in Angola, where the worm was stated to be a common human infection and was described under the native name of *loa.* Since these earlier observations the distribution of *Loa loa* has been found to be quite extensive in Central West Africa, being distributed along the coast from Southern Nigeria, the Cameroons, down to Angola, and from the French Congo inland to Central Tropical Africa (Wellé River district) and possibly to the contiguous border of Uganda. All of the cases reported from the New World are now generally believed to have contracted their infection in the African endemic areas.

Structure and Life Cycle of the Worm.—The adult worms were first studied with care by Looss (1904). The body is cylindrical filiform

and semitransparent, tapering anteriorly to the small terminal mouth, which lacks papillæ. The head, is, however, ornamented with two lateral and four small submedian papillæ (Fig. 245 *A*), which lie in one transverse plane just behind the mouth. The males measure 30 to 34 mm. in length by 0.35 to 0.43 mm. in greatest breadth, which is in the anterior part of the body. The posterior portion tapers gradually towards the caudal end. The females range

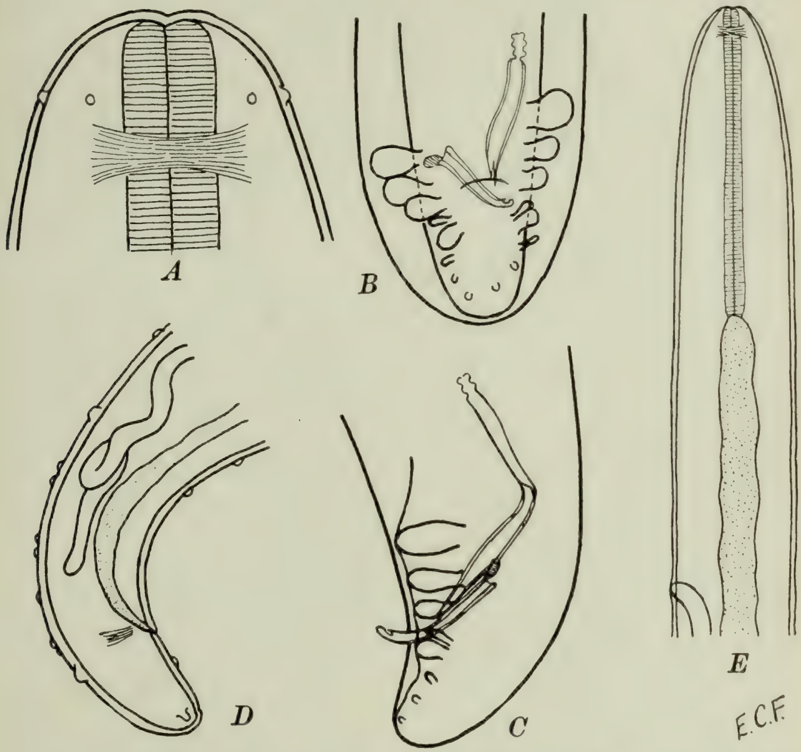


FIG. 245.—*Loa loa*. *A*, anterior extremity of body, showing lateral and submedian papillæ; *B*, posterior end of male worm, ventral view, showing caudal alæ, papillæ and copulatory spicules; *C*, lateral view of male worm; *D*, caudal extremity of female worm, lateral view, showing cuticular bossing, anal opening and posterior coil of genital system; *E*, anterior end of female, lateral view, showing anterior end of intestine and vulvar opening. *A*, *B*, *C*, × 180; *D*, × 64; *E*, × 32. (After Yorke and Maplestone, Nematode Parasites of Vertebrates, courtesy of J. and A. Churchill.)

from 50 to 70 mm. in length and have a maximum diameter of about 0.5 mm. The cuticula is provided with numerous rounded, smooth, translucent bosses, varying greatly in number and arrangement. In the male they are lacking at the two extremities, but in the female they are commonly present at the posterior end and may also be found at the cephalic extremity. The mouth opens directly into a slender muscular esophagus. Posterior to the esophagus is the long

filiform mid-intestine, which attains a diameter of 65 μ and is continued at its caudal extremity into a short attenuate rectum.

The tail of the male (Fig. 245 *B, C*) is curved somewhat ventrad. It is provided with lateral alate expansions of the cuticula. The cloacal opening lies mid-ventral in position, about 80 μ from the posterior end of the worm. It is surrounded by 5 pairs of somewhat asymmetrically placed pedunculated papillæ, while about 3 pairs of small sessile papillæ are situated toward the caudal tip. The two copulatory spicules are unequal, measuring 123 to 176 μ and 88 to 113 μ respectively. The ano-genital orifice is guarded by a powerful sphincter. The posterior end of the female (Fig. 245 *D*) is broadly rounded and has a pair of terminal papillæ. The vulvar opening in the female is situated some 2.5 mm. from the anterior end (Fig. 245 *E*). The vagina extends posteriad for a distance of 9 mm., where it bifurcates to form the uteri. These latter, with their inner receptacula-seminis, oviducts, and ovarian-tubule continuations, practically fill the entire body. The uteri contain all stages of the developing embryos, which are enclosed in an egg membrane. This membrane in the fully embryonated egg becomes elongated into the "sheath" which surrounds the microfilariæ.

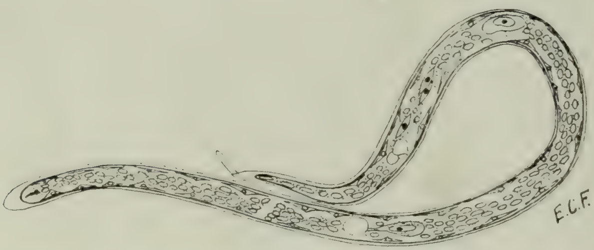


FIG. 246.—Microfilaria of *Loa loa*. For explanation of landmarks see Fig. 235. × 666. (After Fülleborn, Archiv f. Schiffs- u. Tropen-Hygiene.)

The microfilariæ, which are discharged into the passages formed by the worms in their migrations, reach the peripheral bloodvessels, in which they are most commonly found during certain parts of the day (9 A.M. to 2 P.M.). This phenomenon has been responsible for the designation of these larvæ as *Microfilaria diurna*. The microfilariæ are similar in size (250 to 300 μ by 6 to 8.5 μ) to the corresponding larvæ of *Wuchereria bancrofti* but differ specifically in internal organization. These points of difference were first carefully studied by Fülleborn (1913). They are illustrated in the accompanying figure (Fig. 246). More recently Sharp (1923) has made a careful comparison in both living and fixed preparations of the affinity of the various critical structures of the two species of larvæ to dyes. The essential differences which Sharp has listed are as follows:

Differences Between Mf. bancrofti and Mf. loa.
(Adapted from Sharp.)

Microfilaria bancrofti.	*Microfilaria loa.*
1. Possesses a sheath of a filigree structure, which stains a brilliant red with dilute Giemsa.	1. Possesses a sheath which differs in structure from that of *Mf. bancrofti*, and which does *not* stain at all with dilute Giemsa.
2. Worm-like organism.	2. Snake-like organism.
3. Lashing, non-progressive movements.	3. Lashing, undulatory movements by which it can rapidly cross a slide.
4. A long and, when sheathless, a very slender cylindrical organism of perfectly regular uniform girth. No tail, but posterior third tapers to a fine point.	4. A long, slender, non-cylindrical organism of varying girth, with a broad head and two definite humps at the "V" and tail spots. Tail short, whip-like and flexed.
5. "V" spot (*e. g.*, excretory bladder) and tail spot (*e. g.*, anal pore) readily distinguished after staining with dilute Giemsa. The aniline dyes are specially suitable for bringing out the structure of the spots and of the central core.	5. "V" spot, after staining with dilute Giemsa, seen to be a hollow viscus with a chromatin-staining body on its outer side, the whole forming a considerable swelling twice the girth of the parasite. The tail spot similar but smaller, and always oval in outline.
6. Always disposed in graceful sweeping curves.	6. Assumes, as a rule, a stiff and ungraceful attitude unless killed very slowly.
7. Nuclei very discrete, round or square, two or three abreast, and quite noticeably uniform in numbers and position.	7. Nuclei of central column of cells, large, oval and disposed like a bunch of dates on main stem, but stain more deeply than those of *Mf. bancrofti.*
8. Nuclei of cuticular cells are never seen.	8. Nuclei of cuticular cells can be easily distinguished when stained with dilute Giemsa.
9. The red staining mass of Fülleborn can be seen, if suitably stained, as a series of discrete nuclei on a blue background, extending for one-tenth the length of the worm.	9. Never exhibits the red granular mass or "Innerkörper" however stained.
10. Cephalic end the same width as the rest of the creature.	10. Cephalic end broad and flat, resembling the head of a viper.
11. Remains alive and unstained in 1 in 1000 methylene blue for many hours. After four or more hours two round cells at the "V" spot stain faintly.	11. Exhibits a marked affinity for methylene blue, which it readily absorbs while alive in a few minutes. Various groups of cells, both cuticular and central, become deeply stained, and, later, on reduction, become colorless once more.

Differences Between Mf. bancrofti and Mf. loa. (Adapted from Sharp.)—*Continued.*

Microfilaria bancrofti.	*Microfilaria loa.*
12. Section of the living embryo produces the same "clean fracture" as does section of the dead animal after staining.	12. When sectioned in life and then stained with dilute Giemsa, the free ends present the appearance of a purple cauliflower.
13. The embryos are more commonly found at night than in the day.	13. Diurnal periodicity does occur, but it is not a conspicuous characteristic of the larva.
14. Embryos are found in hydrocele fluid.	14. Embryos never found in hydrocele fluid.

The life cycle of *Loa loa* involves certain species of mango flies (*Chrysops dimidiata*, *C. silacea* and possibly other species of this genus), which are day-feeders. As early as 1895 Manson suggested on epidemiological grounds that *Chrysops dimidiata* was the intermediate host of the infection. The work of Leiper on the West Coast of Africa in 1912–1913 lent certain experimental proof to this view, while at the same time it showed that other biting insects were probably unsuitable hosts. Leiper's experiments were confirmed by Kleine (1915) who investigated the problem in the Cameroons. Finally the detailed transmission studies of the Connals (1921–1922) have given a complete history of the insect phase of the life cycle. The microfilariæ are taken into the stomach of the Chrysops when the fly takes a blood-meal of a patient harboring the microfilariæ in his peripheral blood. Shortly after being ingested the larvæ break their way out of their "sheaths." They then increase somewhat in size, make their way through the stomach wall, and proceed to the muscular and connective tissue of the abdomen and to a lesser degree the tissues of the thorax, where they become thickened and bent on themselves, while the caudal extremity develops a sickle-shaped termination. During the third day the alimentary tract becomes complete. From the fourth day increase in length takes place and by the fifth day the larva is usually coiled into a corkscrew spiral. On the sixth day the tight coiling is resolved into gentle curves. The sheath (*sensu stricto*) is cast off in small pieces, the sharply-pointed tail disappears and the caudal extremity becomes rounded and trilobed. From the seventh day onward a marked increase in length occurs, accompanied by a slight decrease in breadth. The larvæ now migrate towards the head, where the mature ones may be found in largest numbers about the tenth day. These larvæ measure 2 mm. in length by 25 to 27 μ in breadth. The worms are now ready to leave the fly

when the host takes a blood-meal. They rapidly make their way down through the labium, and emerge as white glistening threads, their numbers in heavily infected flies amounting to several hundred. While most of the mature larvæ leave the dipteran host in one migration on or about the tenth day, the fly may remain infective for a period of five days. Within sixty seconds after the worms have emerged from the fly they have disappeared under the skin of the mammalian host. Attempts to infect monkeys, rabbits and guinea-pigs have been unsuccessful, although the larvæ readily penetrate the skin of the guinea-pig. Nothing is known of the development of the worms once they have reached the subcutaneous areas of the human host. The life of the adult worms in man may be as much as fifteen years or more.

Pathogenicity and Symptomatology.—The adult worms ordinarily live in the subcutaneous connective tissue of man, where they migrate back and forth, for the most part without causing noticeable symptoms. They have been found in the extremities, the trunk and even the scrotum, but appear to have a certain predilection for the head. They are temporarily bothersome when passing across the eyeball or over the bridge of the nose. Likewise, most cases give a history of fugitive swellings (Calabar swellings), which may become as large as a half goose-egg, are painless but hot, do not pit, and disappear in two or three days. The exact relationship of the worms to these ephemeral swellings remains unexplained.

Diagnosis.—This is made on recovery of one of the worms from its migratory tract or more commonly by the differentiation from other microfilariæ of the larvæ recovered in blood films.

Therapeusis.—Inadequately studied.

Prophylaxis.—The incrimination of the mango fly, Chrysops, as the intermediate host, resolves the preventive aspects of the infection into (1) protection from bites of the fly in infected areas and (2) anti-Chrysops campaigns.

Subfamily 4. Setariinæ. Yorke and Maplestone, 1926, **Emend.**—This group of filarioid nematodes is characterized by having either a smooth or bossed cuticula and by possessing a peribuccal annulus, or spinous or other ornamentations around the mouth. The copulatory spicules of the male are unequal, and the vulva of the female is in the esophageal region. The caudal extremity of the female is provided with a pair of lateral appendages. The microfilariæ are "unsheathed." These species are parasitic in the adult stage in the tissues or body cavity of various groups of vertebrates, and in insects during a larval stage. Two species, *Acanthocheilonema perstans* and *Mansonella ozzardi,* have been recorded from man.

Genus Acanthocheilonema Cobbold, 1870.
(genus from αχανθα, spine, χείλος, lip and νεμα, thread).

41. **Acanthocheilonema perstans** (Manson, 1891), Railliet, Henry and Langeron, 1912.

Synonyms.—*Filaria sanguinis hominis minor* Manson, 1891; *Filaria sanguinis hominis perstans* Manson, 1891; *Filaria ozzardi* var. *truncata* Manson, 1897; *Dipetalonema perstans* (Manson, 1891) Yorke and Maplestone, 1926.

Historical and Nosogeographical.—This species of filarioid nematode was discovered by Daniels in Demeraran aborigines in British Guiana and was first described and named by Manson, who also first identified the microfilariæ in the blood of negroes from the Congo. Since that day the infection has been found to be prevalent in a considerable part of Tropical Africa, including the West Coast from Senegal to Angola and a broad belt of territory across to the head-waters of the White Nile on the north and to the Zambesi Valley on the south. It has also been reported from western coastal Venezuela, Trinidad, throughout the lower stretches of the Amazon Valley and in the north-central Argentine, as well as from Dutch New Guinea, Algiers and Tunis. (See map, Fig. 233). There appear to be no recent records from the region of British Guiana where the adult worm was first found. In Africa the microfilaria is frequently associated in blood-films with the larvæ of *Wuchereria bancrofti* and of *Loa loa;* in South America, with *Microfilaria ozzardi.*

Structure and Life Cycle of the Worm.—The adult worms are long cylindrical, filiform nematodes, with smooth cuticula and a simple unarmed oral extremity, covered with a cuticular shield bearing on each side a large lateral and a pair of submedian papillæ (Fig. 247 *A*). The tail in both sexes in recurved ventrad, and the cuticula of the extreme caudal tip is split, so as to form a pair of minute triangular flaps, which are devoid of a supporting core (Fig. 247 *B*). The male measures 45 mm. in length by 60 μ in greatest breadth, with a cephalic diameter of 40 μ. In the cloacal region there are 4 pairs of preanal papillæ and 1 postanal pair. The copulatory spicules are rod-like and very unequal in length (Fig. 247 *C*). The female has a length measurement of 70 to 80 mm. and a greatest breadth of 120 μ, while the diameter of the bluntly rounded head is 70 μ. The vulva is situated 0.6 mm. from the cephalic end. The adult worms live in the mesentery and in the perirenal and retroperitoneal tissues and in the pericardium, where they are sometimes found in considerable numbers. In addition to man the parasite has been reported from the gorilla and from anthropoid apes.

The microfilariæ of *A. perstans* are non-periodic but their numbers in the blood vary at different times. They have a greater predilection for the heart, lungs and greater arteries than for the peripheral

circulation. These larvæ (Fig. 247 *D*) measure about 200 μ by 4.5 μ, and are capable of remarkable contraction and elongation. They are conspicuously smaller than the microfilariæ of *Wuchereria bancrofti* and *Loa loa,* and lack a "sheath" (*i. e.,* they have hatched on oviposition and are, therefore, truly viviparous). The head end is blunt and the tapering of the body which ends in the tail begins some distance anterior to the equatorial plane. There is no cephalic lancet. The excretory pore is about 30 μ from the head end and the anal pore is inconspicuous. The genital cells are diffi-

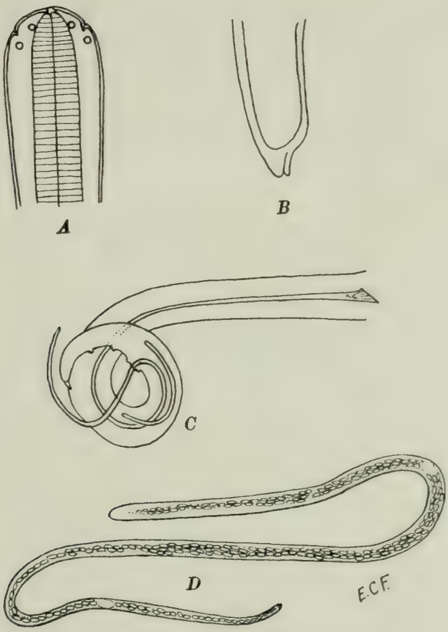


FIG. 247.—*Acanthocheilonema perstans.* *A*, anterior end of worm, with papillæ; *B*, caudal end of female worm, with cuticular flaps; *C*, caudal extremity of male worm, showing caudal papillæ and copulatory spicules; *D*, microfilaria from periphera, blood of patient. (*A*, *B*, *C*, after Leiper, Trans. Roy. Soc. Med. and Hyg.; *D*, × 666l original adaptation from Looss.)

cult to demonstrate. In addition to the ordinary wriggling movement characteristic of all microfilariæ this larva also travels about through the blood as the microfilariæ of *Wuchereria bancrofti* do in the mosquito's stomach. A period of development in an intermediate insect host is necessary before the larvæ become infective again for man. Partial development has been obtained in *Culex pipiens,* also by Low in *Mansonia uniformis* and by Fülleborn in *Anopheles maculipennis,* while Sharp (1928) has obtained complete metamorphosis in *Culicoides austeni,* including emergence of the

mature larvæ from the proboscis seven to ten days after experimental infection of the flies. About 7 per cent of the wild *C. austeni* at Mamfe, Cameroon, have been found to be naturally infected. The related species, *C. grahami,* is probably an equally good intermediate host.

Pathogenicity and Symptomatology.—Not known, but certain workers in endemic areas would assign to the worm the causative rôle in certain cases of lymph varix.

Diagnosis.—On finding non-periodic microfilariæ of this specific type in peripheral blood.

Therapeusis.—No specific treatment is known.

Prophylaxis.—This filaria, although widely distributed, appears to be dependent on intermediate insect hosts which breed only in forest jungle or swamps. The gradual reduction of such areas will probably be accompanied by a corresponding diminution in infection with *Acanthocheilonema perstans.*

Genus Mansonella gen. nov.

genus named for Sir Patrick Manson).

The genus *Mansonella* as here designated, is a member of the subfamily **Setariinæ**, with the characters of this subfamily but distinguished by the presence of paired fleshy flaps lateral to the caudal extremity of the adult female worm, and by unsheathed microfilariæ with pointed tails lacking a nuclear core for the terminal 10 to 20 μ.

42. **Mansonella ozzardi** (Manson, 1897) gen. nom. nov.

Synonyms.—*Filaria ozzardi* Manson, 1897 (*pro parte*); *Filaria Demarquayi* Manson, 1897 (*nec* Zune, 1892); *Filaria juncea* Railliet, 1918; *Filaria tucumana* Biglieri and Araoz, 1917.

This filaria was first studied in the larval condition by Manson, in blood obtained by Ozzard from Carib Indians from the interior of British Guiana. The microfilaria was at first believed to be different from that obtained by Newsam from natives of St. Vincent which was designated *F. demarquayi* by Manson, but the studies of Penel and of Leiper have shown that the two forms are identical. Since the name *demarquayi* was previously used by Zune (1892) for another human microfilaria (possibly *Mf. bancrofti*) it is not available for Manson's species, which becomes *M. ozzardi.* The distribution of this species includes parts of the West Indies, and adjacent coastal South America (particularly British Guiana, where it is frequently associated with *Acanthocheilonema perstans*). The microfilaria, which is found in 25 to 30 per cent of the natives of the northern provinces of Argentina and has been described as *F. tucumana,* is probably the same species. Manson, as well as

Seligmann, report this species from New Guinea, but this latter species may be *Filaria malayi*, which has been described from the Celibes.

In the species *Mansonella ozzardi* the male is known only from a single posterior fragment of 38 mm., with a maximum diameter of 0.2 mm. The tail is strongly recurved, and becomes gradually narrowed up to 0.27 mm. from the extremity, where it abruptly rounds off into a slightly bulbous termination. The two copulatory spicules, presumably unequal, have not been described in detail. The female worm has a length of 65 to 81 mm. and a maximum breadth of 0.21 to 0.25 mm. The cuticula is smooth. The head is unarmed. The small mouth leads directly into the esophagus.

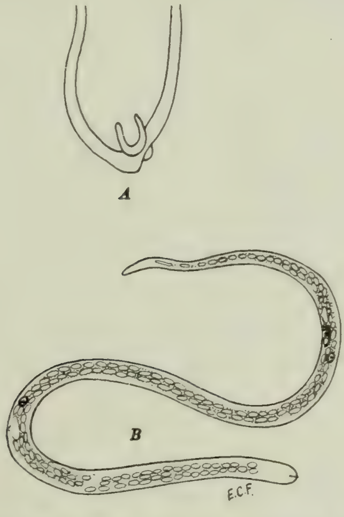


FIG. 248.—*Mansonella ozzardi*. *A*, posterior extremity of female, enlarged (after Leiper, Trans. Royal Soc. of Med. and Hyg.); *B*, microfilaria, × 666. (Original.)

The anal opening is on the summit of a small papilla, 0.25 mm. from the posterior extremity. On either side of the caudal extremity there is one of a pair of lappets with a fleshy core (Fig. 248*A*). The vulva is situated 0.71 to 0.76 mm. from the anterior end of the female worm. The vagina is externally straight but more or less irregular in contour as it proceeds to the junction with the two uterine tubes. The small oval eggs measure 21 by 8.4 μ. Various stages of development are found in successive parts of the uteri from within outward. The fully-developed larva escapes from the egg membrane before oviposition takes place so that the microfilaria is "unsheathed." This microfilaria is very active in fresh blood-films, elongating and constantly coiling on itself. The cephalic

extremity is armed with a minute retractile stylet and is provided with a poorly-developed prepuce. The caudal end is pointed to somewhat the same degree as that of *Microfilaria perstans.* Both the oral and the caudal extremities are free of nuclei (2.5 per cent and 98.0 per cent respectively). The excretory pore is situated at about the junction of the anterior and the equatorial thirds of the body (31.5 per cent) with the excretory cell just posterior in position (35.0 per cent). The G_1 cell is at 69.3 per cent and the G_4 cells at 79.2 per cent, the latter being immediately in front of the anal pore (79.4 per cent). The larvæ of this species are non-periodic. According to Low and Vincent *Aëdes ægypti* (= *Stegomyia fasciata*) is the insect host, while Fülleborn has obtained development in *Anopheles maculipennis,* at least as far as the sausage-shaped larvæ.

Pathogenicity and Symptomatology.—The adult worms have been recovered from the mesentery and the subperitoneal tissue of the anterior abdominal wall. The worms are believed to be non-pathogenic.

Diagnosis.—On the discovery of microfilariæ of this species in peripheral blood. These larvæ must be differentiated from those of *Wuchereria bancrofti* and *Acanthocheilonema perstans,* with which they are frequently associated, and from *Mf. malayi,* which is "sheathed" and has nuclei in the caudal tip.

Therapeusis.—Unstudied.

Prophylaxis.—Unstudied. Undoubtedly involves protection of individuals in endemic areas from mosquito bites and the more general problem of mosquito eradication.

LARVAL FILARIIDÆ.

The species described under this heading have been observed only in the larval stage but have been so definitely described as to leave no doubt that they are members of the family **Filariidæ.**

43. **Microfilaria malayi** (Brug, 1927).

This microfilaria was obtained by Lichtenstein from natives in the neighborhood of Celibes and was studied by Brug, who found it to differ from the common microfilaria (*Mf. bancrofti*) and designated it *Filaria malayi.* The description presented here is from thick blood smears prepared by Brug and studied by the present author (Fig. 249). The larvæ measure 220 to 260 μ in length by 5 to 6 μ in greatest breadth. They are invested with a sheath, which is very much longer than the larvæ. The cuticula is very delicately striated. The anterior extremity is bluntly rounded and bears a double stylet process. There are no nuclei in the anterior-most 12 to 16 μ. The excretory pore is about 28 per cent distant from the anterior extremity, and the anal pore, about 76 per cent.

(Brug's corresponding measurements are 28.6 and 77.7). From the region of the anal pore the body decreases to an acuminate caudal extremity. At the extreme caudal termination there is an elongate nucleus and about 10 μ in front of this nucleus there is an oval nucleus, the two being much more darkly stained than the other nuclei of the microfilaria. Genital cells (G_1, G_2-G_4) can be seen with difficulty anterior to the anal pore. The adult worm is unknown, but Lichtenstein states that *Culex fatigans* serves as intermediate host. The exact systematic position of the worm and the pathogenicity of the infection, which affects a high percentage of persons in the endemic area, require study.

FIG. 249.—*Microfilaria malayi*. For explanation see Fig. 235. × 666. (Original from a blood-film from Celibes, obtained by Brug.)

44. **Microfilaria streptocerca** (Macfie and Corson, 1922) Stiles and Hassall, 1926.

Synonyms.—*Agamofilaria streptocerca* Macfie and Corson, 1922; *Microfilaria* of *Onchocerca volvulus* of Manson-Bahr, 1925.

This microfilaria was first described by Macfie and Corson from biopsy of natives of the Gold Coast, where *Onchocerca volvulus*, *Acanthocheilonema perstans* and other human microfilariæ occur. Forty-four per cent infection was found in the subjects examined, who were all in good health. The larvæ were present only in the cutis or corium. They are sheathless microfilariæ, tapering both anteriorly and posteriorly, with a transversely striated cuticula. When fixed the body is relatively straight except at the posterior end which is strongly bent in a shepherd's-crook curve. They range in length from 180 to 240 μ and measure about 3 μ in cross-section diameter. The anterior extremity is bluntly rounded. No oral stylet has been seen. The anatomical landmarks which have been found are as follows (expressed in percentage distance from the anterior end): nerve ring, 26.9; excretory pore, 34.1; first genital

cell, 69.2; anal pore, 86.2. The posterior extremity is blunt and contains oval nuclei to within 1 μ of the end. Sharp (1927) has found that the capacity of this larva for vital dyes is very slight, like that of *Wuchereria bancrofti,* as contrasted with the strong affinity of the larvæ of *O. volvulus, Loa loa* and *A. perstans.* According to Sharp this species does not utilize *Simulium damnosum* as an intermediate host.

Family FUELLEBORNIIDÆ nom. nov.

This family of filarioid nematodes contains those forms in which the female worm is enormously longer than the male. The posterior end of the male is sharply recurved ventrad. The copulatory spicules are conspicuously unequal and dissimilar. A few peri-cloacal papillæ are probably always present. In the gravid females the uteri come to fill practically the entire body, the vulva becomes atrophied and the vagina disintegrated, and the embryos are discharged by prolapse of the uteri from a rupture of the body-wall near the mouth. The anus is also non-functional in gravid females. The females are ovoviviparous. The larvæ of this family pass an intermediate stage in fresh-water Copepoda, which, when swallowed in raw water, convey the infection to the definitive host, in which the worms mature in the subcutaneous tissues. There are only two recognized genera of this family, *Fuellebornius* (*e. g., Dracunculus* auct.), and *Philometra.* The classical representative of the former, *F. medinensis,* is an important human parasite.

GENUS FUELLEBORNIUS LEIPER, 1926, PRO DRACUNCULUS AUCT. (genus named for Professor F. Fülleborn).

45. **Fuellebornius medinensis** (Linnæus, 1758) Leiper, 1926.

Synonyms.—*Gordius medinensis* Linnæus, 1758 (*vel* 1785); (?) *Dracunculus medinensis* (Linn., 1758) Gallandant, 1773; (?) *Vena medinensis* (Linn., 1758) Gallandant, 1773; *Dracunculus græcorum* Gruner, 1777; *Filaria medinensis* (Linn., 1758) Gmelin, 1790; *Furia vena medinensis* (Linn., 1758) Modeer, 1795; *Filaria æthiopica* Valenciennes, 1856; *Dracunculus æthiopicus* (Val., 1856) Schneidemuehl, 1896; *Vermiculus capsularis* Dunglison, 1895.

Historical and Nosogeographical.—The Medina or Guinea worm was one of the classical helminths of antiquity. Commonly referred to as the serpent-worm (*vide* reference to the worm by Moses), or the dragon-worm (hence the name of the disease dracontiasis), the infection is still prevalent in the areas where it existed in ancient times, but, in addition, has been spread to tropical America where it has become established. The present endemic areas include extensive regions in the Nile Valley, the environs of Lake Chad,

and other parts of Central Equatorial Africa, as well as the West Coast of Africa from Mauretania to Gabun; Arabia, both the part

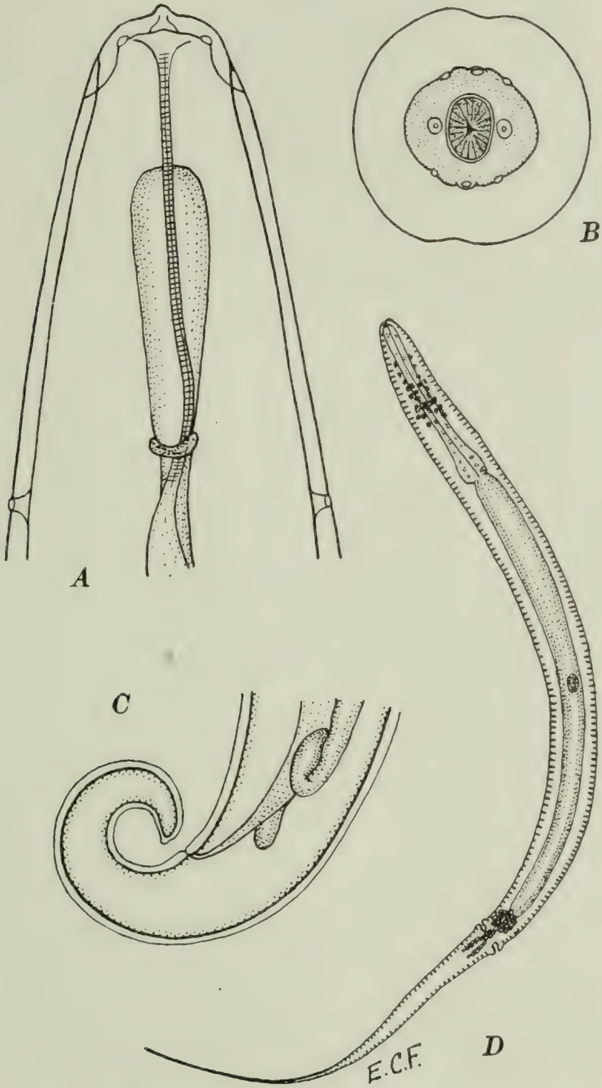


Fig. 250.—*Fuellebornius medinensis.* *A*, anterior end of female, ventral view, showing cephalic shield and papillæ, cervical papillæ, esophagus and esophageal gland; *B*, head-end view of worm; *C*, posterior end of female with recurved tip, posterior extremity of ovarian tubule and rectum with anal opening; *D*, larva of the dracunculus, as discharged from the parent worm, with esophagus, mid-intestine, anal opening and anal papillæ, nerve ring and genital primordium. *A–C*, × 64 *D*, × 200. (Original adaptations.)

adjacent to the Red Sea and the interior; unsurveyed stretches of Persia; India, comprising various areas on the west coast but particularly around Bombay, the Central Province, parts of the Northwest Province, and areas as far north as the foot of the Himalayas, Hyderabad and parts of the Madras Presidency, but not including the east coast; and, by introduction, the islands of the Caribbean, the Guianas and the state of Bahia (Brazil). In Africa the village ponds seem to be particularly responsible for the infection, while in India the step-wells are said to be involved.

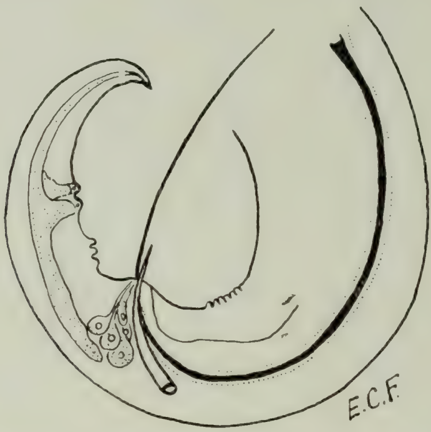


FIG. 251.—Posterior end of *Fuellebornius globocephalus*. × 185. (After Mackin, Journal of Parasitology.)

Structure of the Adult Worms.—The adult worms live in the subcutaneous connective tissue, but at times may invade the deeper layers. The gravid females measure from 70 to 120 cm. in length (with an average somewhat under a meter) by 0.9 to 1.7 mm. in diameter. Male worms have been definitely reported on only two occasions, a single mature worm measuring 40 mm. in a natural infection from India, and two immature worms from an experimental infection in the monkey (Leiper's case), with a length of 22 mm. The worms are elongate cylindrical threads or cords, bluntly rounded at the anterior extremity and recurved ventrad at the caudal end which serves as an anchor for the worms. The cuticula is smooth. The anterior end (Fig. 250 *A*, *B*) has a cephalic shield. The minute triangular mouth lies in an oval or quadrate prominence and is surrounded by 4 pairs of papillæ (Fig. 250 *B*), consisting of a large dorso-ventral pair, a small median-lateral pair and 2 small submedian-lateral pairs. A pair of lateral cervical papillæ is found just behind the plane of the nerve ring, only 1 mm. from the anterior end. The mouth opens directly into the narrow muscular esophagus,

which merges with the glandular esophagus just in front of the cervical papillæ. The latter proceeds some distance backward before it is continued as the long cylindrical mid-intestine, which empties *via* a short conical rectum, and opens through a minute anal aperture. In the related species, *Fuellebornius globocephalus* (Mackin, 1927) a pair and an additional unpaired esophageal glands are described, the latter extending to near the cephalic end. The structure of the male of *F. medinensis* has never been described. It seems likely, however, that it corresponds in many respects to the male of *F. globocephalus,* which, according to Mackin (1927), is characterized by having a single straight genital tube, with regions differentiated into testis and vas deferens; a right copulatory spicule which is a non-alate broadly curved needle-shaped object measuring 0.8 mm. in length by 5 μ in diameter; and a left spicule (0.2 mm. long by 10 μ thick) which is a hollow tubule at the proximal end and more medianly appears as two tubules joined laterally, merging distally into a fine point (Fig. 251).

When the female is gravid with larvæ and is ready to discharge them, the cephalic end of the worm approaches the skin layer, producing a small papular induration and vesiculation of the dermis. Such papules are usually found on the extremities of the body. Within twenty-four hours this papule has developed into a blister, which may soon rupture or may increase in size for four or five days. Sooner or later, however, the eschar breaks open near the center. If the infected member then comes in contact with fresh water, a delicate loop of uterus, which has prolapsed through a ruptured part of the worm's body near the head, will be extruded, will burst open and discharge motile larvæ into the water. Successive discharges of larvæ will typically occur whenever the head of the ulcer comes in contact with water until the entire progeny have been evacuated.

Life Cycle of the Worm.—The larvæ which are set free into the water (Fig. 250*D*) are filiform wiry objects, measuring 500 to 750 μ in length by 15 to 25 μ in greatest diameter, with a bluntly rounded anterior end and a long attenuate caudal process. Esophagus, mid-intestine, anal pore, nerve ring, and genital primordium may be recognized, as well as a pair of anal papillæ set into deep pockets one on either side of the anal opening. The cuticula is conspicuously marked with transverse striations. The larva moves about with a stiff wiry motion, at times coiling on itself to form a Greek letter "α". It has no boring apparatus, or other means of gaining active entrance into the intermediate host. If, however, specimens of an appropriate species of cyclops are present in the water, a condition which is frequently fulfilled in endemic areas, some of the larvæ are ingested and on reaching the intestine of the cyclops, break through the soft wall and come to lie in the celomic cavity of

these animals. More than five or six of the larvæ usually cause the death of the cyclops. In suitable species of cyclops (*C. quadricornis*, *C. strenuus*, *C. viridis*, *C. bicuspidatus*, *et al.*) the larvæ proceed to undergo metamorphosis, with a loss of the striated cuticula about the eighth day and two days later the development of a delicate enveloping sheath. Subsequently they become quiescent and show no inclination to quit the cyclops. If, however, after metamorphosis of the larvæ, the cyclops with their parasitic progeny are accidentally ingested by man in raw water, the action of the gastric juice causes them to become active again, they escape from the semi-digested cyclops' body, penetrate the wall of the digestive tract (whether the stomach or duodenal wall, is not clear), and migrate through the tissues, coming to lodge in the subcutaneous connective tissue, where a period of ten to fourteen months is required before the female worms are mature and are ready to discharge their young.

In addition to the human host dracunculus-worms have been reported from dogs, horses, cattle, leopards, monkeys, baboons, and the cobra. It seems altogether possible, however, that some of these forms are species other than *Fuellebornius medinensis*, particularly the specimens from the cobra. Leiper (1907) was successful in infecting a monkey by feeding cyclops containing mature dracunculus larvæ, but Fairley and Liston (1925) failed to infect *Macacus sinicus*.

Pathogenicity and Symptomatology.—Of the many clinical studies on Medina-worm infection only Fairley and Liston (1925) have investigated this phase of the subject adequately. From an analysis of 140 cases these workers have shown that the incubation period is essentially symptomless, and that the onset of symptoms occurs just a few hours preceding localized manifestations of the infection under the skin. The prodromal symptoms consist of erythema and urticaria, the latter being almost invariably generalized, with an associated intolerable itchiness; nausea, vomiting and diarrhea; severe dyspnea; giddiness and syncope—all of which are believed to be due to toxic secretions of the worm which have been absorbed into the system. The localized lesions become evident a few hours after the onset of the systemic symptoms or at times coincident with them. These lesions consist of small reddish papules on the skin with a dome-like vesicular center and an indurated margin, with a diameter of 2 mm. to 7 cm., depending on the amount of exudation underneath the blister and the length of time before the eschar ruptures. These lesions are most commonly situated on the lower extremities, but may occur on the upper extremities, the trunk, buttocks, and scrotum. Not infrequently they occur on the sole of the foot or between the metatarsal bones (Fig. 252). The fluid from the cavity of an unruptured lesion is a yellow serum which

is invariably sterile on culture. It usually contains large numbers of mononuclear cells, eosinophiles and polymorphonuclear leukocytes, as well as embryos of *F. medinensis*. The lesion at the moment of spontaneous rupture (Fig. 253) is seen to consist of an outer layer of skin which forms the dome, a concave partly necrosed base, and an intermediate septum of fibro-gelatinous material, the intervening spaces being filled with a fluid exudate (Fairley's "blister fluid"). Near the center of the base is a pore, communicating with an adventitious tunnel in which the female worm is found. The head of the worm at the time of vesicle formation is usually just beneath the base of the lesion or actually protruding into the cavity

FIG. 252.—Dracunculus worm partially removed from a ruptured eschar of the fourth toe. (After Castellani and Chalmers, Tropical Medicine.)

of the vesicle. The rupture of the vesicle relieves toxic symptoms but is usually the occasion for the introduction of pyogenic organisms, which not only invade the cavity of the superficial lesion but travel up the tunnel and thus greatly aggravate the condition. These complications are frequently more serious than the original infection.

Diagnosis.—This cannot be effected until the onset of symptoms with the almost immediate development of local lesions. The method utilized by the female worm in effecting a discharge of the larvæ, as well as the type of larvæ set free, are unique and constitute a specific diagnosis. Old calcified worms may be diagnosed by Roentgen-rays.

Therapeusis.—The systemic symptoms preceding local vesicle formation completely disappear upon administration of adrenalin. Once the lesion has ruptured care should be taken to avoid the invasion of pyogenic organisms. No drug has been successfully used to kill or anesthetize the female worm so that it may be removed intact from its subcutaneous tunnel. Fairley and Liston (l. c.) propose an operative technique by incising the tissues in three or four places overlying the tunnel and withdrawing the worm in parts, care being taken not to draw the portion of the worm which has come in contact with the outer septic crater back into the tunnel.

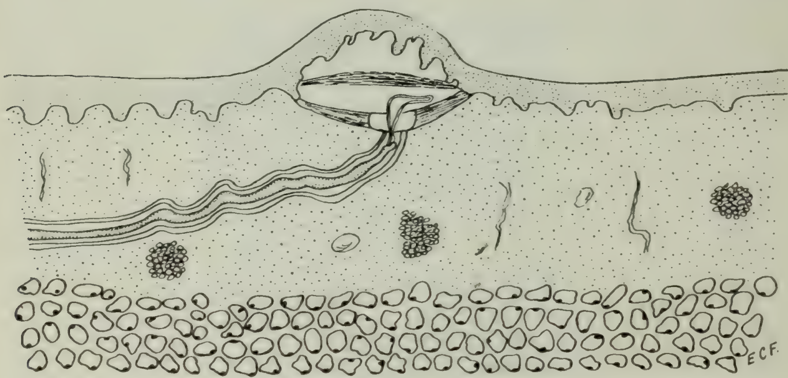


FIG. 253.—Diagrammatic section through dracunculus lesion with the connecting tunnel. (Adapted from Fairley and Liston, Indian Jour. Med. Research.)

Prophylaxis.—Epidemiological evidence in India points to the step-wells as being the most common places of infection with the dracunculus. On the West Coast of Africa the village ponds are believed to be the most likely source of infection. In both regions, however, the actual conditions for propagating the infection are essentially the same, namely, the contact of the body, especially the lower extremities, of infected individuals with water which harbors appropriate species of cyclops and which is used raw for drinking purposes. By confining the water for drinking purposes within a cemented curb, so that the legs of the water-carriers do not come in contact with the household supply and so that the water spilled over the curb cannot flow back into the well, the infection in these principal endemic foci can be reduced to a relatively small incidence. It is possible, also, that the water may be treated with chemicals in amounts sufficient to kill the cyclops without harming its drinking properties.

FILARIOID NEMATODES INADEQUATELY DESCRIBED, RARE OR OF UNCERTAIN IDENTIFICATION.

The following list of immature and larval nematodes is included for reference. Some of these are probably good species but have been inadequately described; others are possibly larval stages of well known species; still others may be purely fictitious. The names "*Filaria*," "*Agamofilaria*" and "*Microfilaria*," as used in this group, are of little or no specific value but are used in the older group sense to indicate that they are filarioid nematodes.

46. **Filaria conjunctivæ** Addario, 1885.—(**Possible Synonyms.**—*F. palpebralis* Pace, 1867; *F. peritonæi hominis* Babes, 1880; *F. inermis* Grassi, 1887; *F. apapillocephala* Condorelli-Francaviglia, 1892.) This form has been reported from cystic tumors of the eyelid, from the eyeball, from the skin of the nose, from the upper arm and from the gastro-splenic mesentery of several persons from Italy, Sicily, Hungary, Macedonia and India. It is an encysted subcutaneous-tissue parasite, of which several females and one male have been recovered. The former measure 16 to 20 cm. in length by 0.5 mm. in breadth. The male had a length measurement of 58 mm. The cuticula is finely striated. The oral end is unarmed, the anus subterminal (0.3 mm. from the caudal extremity) and the vulvar opening of the female 50 to 104 μ from the anterior extremity. The uterus is composed of two branches, filled with embryos measuring 250 μ by 55 μ. The infection in man occasions a burning or itching sensation and, at times, a localized edema.

47. **Filaria extraocularis** Skrjabin, 1917.—(**Synonyms.**—*Loa extraocularis* Skrjabin, 1917.) This form is known only from an immature female obtained from a small tumor of the orbital cavity of a peasant in the Caucasus. The worm measured 14.8 cm. in length by 0.612 mm. in breadth, possessed a finely-striated cuticula, esophagus 935 μ by 85 μ, nerve ring 272 μ from the anterior extremity, anal opening 100 μ from the caudal end and vulva 2.4 mm. from the head.

48. **Agamofilaria georgiana** Stiles, 1907.—This form has been obtained only once, in a negress from Georgia (U. S. A.). Eighteen specimens (sex not specified) were removed from the ankle and instep of the patient. The worms had a length measurement of 32 to 54 mm. and a thickness up to 0.64 mm., and tapered gently toward the rounded ends. The cuticula was smooth. The mouth was encircled by a group of two small lateral and four submedian papillæ. The anus was subterminal.

49. **Agamofilaria oculi** v. Siebold, 1839.—(**Synonyms**: *F. oculi humani* v. Nordmann, 1832, *F. lentis* Diesing, 1851.)—Specimens of this worm are reported three times from the crystalline lens of

man but the descriptions are too inadequate to state whether the worms even belong to the **Filarioidea.**

50. **Filaria taniguchii** Penel, 1904.—(**Synonym**: *F. bancrofti* Taniguchi, 1903, *nec* Cobbold, 1877.)—A single slightly immature female filaria of 68 mm. length and 0.2 mm. diameter was removed by Taniguchi from an inflamed ganglion of the groin of a Japanese patient. The body of the worm was white, transparent, homogeneous and the cuticula finely striated. The mouth was provided with lips, consisting of four lobes, each bearing 2 pairs of very small papillæ. There were no teeth or other armature. The vulva was situated 1.3 mm. from the anterior end. The anal pore was very inconspicuous and was located 0.23 mm. from the caudal extremity. The larvæ within the egg membrane measured 40 by 25 μ. The poles of the enveloping membrane were slightly pointed. The larvæ when elongated measured 290 μ by 7 μ, were "unsheathed" and had a pointed tail. Taniguchi also found "unsheathed" microfilariæ similar to those in the mother worm at times in hydrocele fluid and ganglionic tumefactions, but never in the blood.

51. **Microfilaria philippinensis** Ashburn and Craig, 1906.—This microfilaria from the blood of patients in the Philippines is probably *Mf. bancrofti.*

52. **Microfilaria powelli** Penel, 1905.—This microfilaria from the blood of a Mohammedan policeman in Bombay had a nocturnal periodicity, was "unsheathed," and had a truncated tail. It measured 131 μ by 5.3 μ. It may have been a small or shrunken type of *Mf. bancrofti.*

53. **Microfilaria romanorum** Verdun, 1907.—(**Synonym**: *Mf. romanorum-orientalis* Sarcani, 1888.)—This microfilaria, described as 1 mm. in length, from the blood of a Roumanian, is a very dubious species entity.

54. **Filaria** sp. Parodi and Bonavia, 1920.—This form, described from a single adult female specimen, was extracted from the eye of a woman of French origin in Argentina. The worm measured 110 mm. in length by 0.41 mm. in diameter, had a whitish, finely-striated cuticula, an unarmed mouth and a vulva situated 0.5 mm. from the cephalic end. The embryos *in utero* were "ensheathed," and measured 250 μ by 6 μ. No microfilariæ were found in the conjunctiva, where the parent worm moved about freely. It seems altogether improbable that this is the adult form of *Microfilaria tucumana* Biglieri and Araoz, 1917, obtained from peripheral blood of patients in the North Argentine.

55. **Filaria** sp.—Dumas and Pettil, 1919.—A single male specimen of this form was obtained from the scrotal wall of a French railway employee suffering from hydrocele of the scrotum. Brumpt (1922) believes it to be a parasite of some other host, accidentally developed in man.

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CHAPTER XXIX.

GORDIACEA OR "HAIRWORMS."

Introduction.—The worms of this subclass of the **Nematoda** are familiarly referred to as "hair snakes" or "horse-hair worms," due to the popular belief that they develop from horse hairs which have fallen into drinking troughs, quiet pools, springs or ponds. These worms are elongate wiry objects, buff to dark brown in color, and densely opaque. Their movements are stiff and wiry and at times spring-like. They are interesting biologically in that the immature larval stage is parasitic in various insects, while the adults are free-living. It is the adult stage which has been reported from time to time as "parasitic" in the human intestinal tract.

The adult free-living worms are diecious. They are elongate capillary nematodes, varying in length from 10 to 50 cm. The anterior ends are more or less bluntly rounded; the posterior end of the male is bifurcated behind the anus or at least possesses a dorso-ventral groove, while that of the female is either entire or trilobate. There are no lateral lines. Internally the body cavity is lined with a non-ciliated epithelium; the gonads are not continuous with their ducts, the ova being discharged into the body cavity and then passed into the ducts; the alimentary canal is more or less atrophied in sexually mature worms; a cloaca is present in both sexes. Furthermore, the males lack an accessory genital apparatus.

The sexually mature worms mate in the water, where the eggs are laid in strings. When fully developed the larvæ rupture the egg membrane and escape by means of a beak-like proboscis, provided with rows of large reversed spines. These larvæ bore their way into any animal tissue which is near at hand. In case they penetrate the body of various Orthoptera (and possibly other insects) they first penetrate the adipose tissue, but later migrate to the body cavity of the host, where they moult, metamorphose, and develop into gordius-like worms. Upon approaching maturity they escape from the insect and assume a free-living condition in the water.

The subclass **Gordiacea** v. Siebold, 1848 is composed of two families, **Gordiidæ** Diesing and **Chordodidæ** May.

Family I. GORDIIDÆ Diesing, emend. H. G. May, 1920.

The species of this family have a smooth cuticula, without true areoles; the body bristles are derived from the fibrous cuticula.

The buccal cavity when present is not connected with the intestine. The ovaries are not connected or enclosed by mesenchyme. The posterior end of the male is provided with two projecting lobes or prongs arising behind the anus. A post-anal crescent is present. The caudal end of the female is entire. The larvæ of this family have an elongate body and a pointed caudal extremity. The only genus in the family is *Gordius sensu stricto* (Fig. 254 *A, B*). The following species of this genus have been reported as "parasites" of man: *Gordius aquaticus* Linnæus, 1758, 2 cases from Europe; *G. villoti* Rosa, 1882, 3 cases from Europe; and *G. chilensis* E. Blanchard, 1849, 1 case from Chile, S. America.

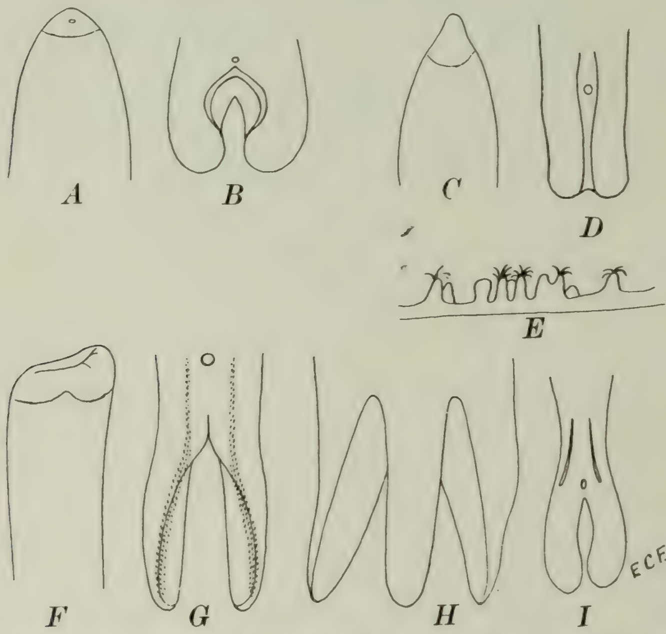

Fig. 254.—Characteristics of Gordiacea. *A*, anterior extremity, and *B*, posterior extremity of *Gordius villoti*, ♂, enlarged (adapted from Camerano, Monografia dei Gordii Accad., Torino, Italy); *C*, anterior extremity, and *D*, posterior extremity of *Cordodes*, ♂, enlarged (after Camerano, Monografia dei Gordii Accad. Torino, Italy); *E*, section through papillæ and cuticular hairs of *Cordodes*, greatly enlarged (original adaptation from Römer); *F*, anterior extremity, and *G*, posterior extremity of *Paragordius varius*, ♂, enlarged (adapted from Stiles and from May); *H*, posterior extremity of *P. varius*, ♀, enlarged (after Stiles); *I*, posterior extremity of *Parachordodes*, ♂, enlarged (after Camerano, Monografia dei Gordii Accad., Torino, Italy).

Family II. CHORDODIDÆ May, 1920.

The species of this family have a rough cuticula, with true areoles; the tubercles and body bristles arise from the non-fibrous cuticula. The ovaries are enclosed by mesenchyme, giving the appearance

of a "double mesentery." The posterior end of the males is forked or provided with a dorso-ventral groove, but they have no post-anal crescent. The caudal end of the female is either entire or provided with three lobes. The larvæ of this family have a short body which is posteriorly rounded and provided with postero-lateral spines. There are three recognized genera which belong to this family, *Chordodes* Creplin, 1847 (Fig. 254*C, D, E*) *Paragordius* Camerano, 1897 (Fig. 254*F, G, H*), and *Parachordodes* Camerano, 1897 (Fig. 254*I*). The following species of this group have been reported as "parasites" of man: *Chordodes capensis* Camerano, 1895, 1 case from British East Africa; *Paragordius tricuspidatus* (Dufour, 1828), 1 case from France; *P. varius* (Leidy, 1851), 4 cases from North America; *P. cinctus* v. Linstow, 1906, 1 case from the Transvaal, S. Africa; *P. areolatus* v. Linstow, 1906, 1 case from S. E. *Africa; Parachordodes tolosanus* (Dujardin, 1842), 2 cases from France, 2 from Italy; *P. violaceus* (Baird, 1853), 1 case from France; *P. pustulosus* (Baird, 1853), 1 case from Italy; and *P. alpestris* (Villot, 1884), 1 case from France.

The "Parasitism" of Gordiacean Worms in Man.—The earlier writers attributed grave consequences to the presence of these worms in the human body. While regarding the condition as one of pseudo-parasitism R. Blanchard believed that the worms developed from larvæ to adults in the human digestive tract. Present information regarding the life cycle of this group renders the latter hypothesis entirely untenable. Adults of these species undoubtedly enter the body accidentally in raw drinking water or in their insect hosts. They may remain undigested for some little while in the digestive tract, during which time their movements and possibly their secretions may occasion mild intestinal disturbances. They may be passed alive *per anum* or vomited. Symptoms believed to have been caused by their presence over long periods of time are probably due to other causes.

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CHAPTER XXX.

ACANTHOCEPHALA OR THORNY-HEADED WORMS.

Introduction.—This class of the Nemathelminthes is composed of species which are characterized by having three distinct parts to the body, the proboscis, the "neck" and the body proper. They are elongate in form, more or less cylindrical or spindle-shaped, and vary in length from a few millimeters to 50 or more centimeters. The proboscis, which is usually retractile into a proboscis-sheath and is commonly armed with several rows of recurved hooks, is at the anterior extremity of the worm and serves as an organ of attachment. A "neck," which intervenes in many species between the proboscis and the body proper, is a short, usually unarmed region, which is separated from the subcuticula by a cuticular fold. The body wall is usually smooth. Internally, a pair of elongate projections from the subcuticula, called the lemnisci, extend posteriad into the body cavity. There are no organs of digestion; food is taken into the body by absorption through the wall. The nerve mass lies within the proboscis sheath. The two sexes are separate. The genital pore is at the posterior extremity. In the male it is frequently surrounded by a campanulate bursa. Two testes, cement glands and cement receptacle comprise the male genital apparatus. In the female there is a suspensory ligament which extends from the anterior to the posterior end. The ovary develops in the larval female, produces a large number of eggs and then degenerates. These eggs, which are provided with three enveloping membranes, lie free in the body cavity, the ones with matured embryos being expelled from the body by means of a muscular organ known as the uterine bell. In addition to the fact that the males are much smaller than the females there are frequently other external characters which distinguish the two sexes, including the shape, the character of proboscis and body spines, and the proboscis-structure.

The Acanthocephala are parasitic during their entire life cycle, with no free-living phase. The eggs, which are passed in the feces of the vertebrate host, are fully embryonated. In order to develop further they must be ingested by certain species of insects or crustaceans, in which they hatch and develop into mature larvæ, which, on ingestion by the appropriate definitive host, attain maturity. Of the three orders provisionally recognized, the species reported from man belong to the **Gigantorhynchata** and the **Echinorhynchata.**

ORDER GIGANTORHYNCHATA NOM. NOV.

Members of this order are characterized by having a reduced proboscis, often composed only of a small part of the proboscis-like structure. The proboscis-sheath is provided with a thick muscular wall, with a prominent cleft near the middle of the venter, and with the insertion near the tip of the proboscis. Retractors emerge from a cleft near the middle of the sheath. A "neck" region is present. The prostatic glands do not consist of a single syncitial mass. The nuclei of the subcuticula and the lemnisci are relatively small and numerous. This order includes the following two families.

Family I. GIGANTORHYNCHIDÆ Hamann, 1892.

Gigantorhynchate forms of large size, with a pseudo-segmentation of the body; with a rudimentary proboscis, represented by only one or two transverse rows of hooks, which are provided with double roots; with filiform multinucleate lemnisci; ellipsoidal, elongate, posteriorly disposed testes and subspherical prostatic glands. This family contains only one genus, *Gigantorhynchus* Hamann, 1892, which has the characters of the family. The species of this family are parasitic in mammals but none have been reported from man.

Family II. OLIGACANTHORHYNCHIDÆ Southwell and Macfie, 1925.

Gigantorhynchate forms of variable size, with a more or less rugose body; with a proboscis subspherical or compressed, armed with five or six transverse rows of hooks, of which all but the basal ones have double roots; with a short, unarmed "neck" region; with ellipsoidal or cylindrical testes and eight ellipsoidal or compressed prostatic glands. The species of this family are parasitic in mammals and birds. Of the three genera of this family, *Oligacanthorhynchus, Macracanthorhynchus* and *Prosthenorchis,* the species reported from man belongs to the genus *Macracanthorhynchus* Travassos, 1917, which is distinguished by having a well-marked sexual dimorphism, the females being very large and spirally coiled, and the males small and comma-shaped; by having relatively short and flat lemnisci, testes some distance anterior to the prostatic glands and the male genitalia occupying the greater portion of the body cavity.

GENUS MACRACANTHORHYNCHUS TRAVASSOS, 1916.
(genus from μαχρός, long αχανθα, spine, ρύγχος, proboscis).

Macracanthorhynchus hirudinaceus (Pallas, 1781) Travassos, 1917.

Synonyms.—*Tænia hæruca* Pallas, 1766 preocc., *pro parte; Tænia hirudinacea* Pallas, 1781; *Echinorhynchus gigas* Bloch, 1782; *Gigantorhynchus gigas* (Bloch, 1782) Hartmann, 1892; *Gigantorhynchus hirudinaceus* (Pallas, 1781) Railliet, 1893; *Echinorhynchus* sp. from man, Lambl, 1859.

The giant thorn-headed worm (Fig. 255) is milky-white in color, slightly flattened dorso-ventrally and rugose in appearance, with a transverse pseudo-segmentation. The males measure 5 to 10 cm. in

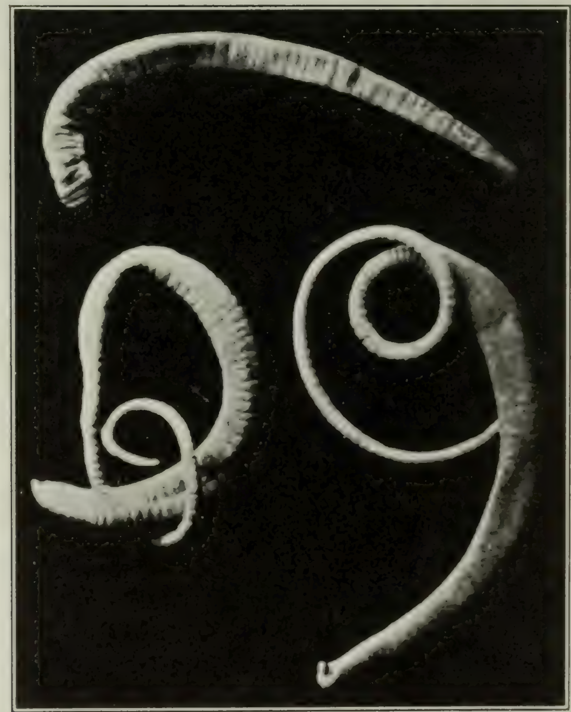

FIG. 255.—Photograph of *Macracanthorhynchus hirudinaceus*. Note the small male superimposed on one of the females. Two-thirds natural size. (After Travassos in Reviste Vet. e Zoötechnica, 1920.)

length by 3 to 5 mm. in breadth, and the females, 20 to 65 cm. in length by 4 to 10 mm. in breadth. The proboscis, which is sunken into the intestinal wall of the host and which usually becomes more or less introverted when the worm is detached from the host tissue, is provided with five or six series of recurved spines, arranged more or less quincuncially. Posteriorly the males are provided with a campanulate bursa copulatrix. The posterior extremity of the females is obtusely rounded. The ellipsoidal eggs measure 80 to 100 μ in length by slightly more than one-half that amount in

diameter. They are fully embryonated when oviposited (Fig. 256) and are provided with three embryonic envelopes. They readily hatch in various species of coleopterous larvæ and proceed to develop into mature larvæ. In Europe *Melolontha vulgaris* has been found naturally infected; in the United States *Lachnosterna arcuata* has been found to be a suitable intermediate host; in Argentina, *Diloboderus abderus* (Sturm), *Phanæus splendidulus* (Fabr.) and *Gromphas lacordairei* Brull have been successfully utilized by Wölffhügel. On ingestion of these infected larvæ the mammalian host becomes infected. The worm is practically cosmopolitan in distribution. The pig, the wild boar and the peccary are the natural definitive hosts. Human cases have been reported by Lambl (1859, *Echinorhynchus* from man), and by Lindemann (1865), the latter authority stating that the infection is common among the inhabitants of the Volga Valley in Southern Russia, where Schneider has found that Melolontha is eaten raw. However these reports have not been confirmed and it is uncertain if human infection actually occurs.

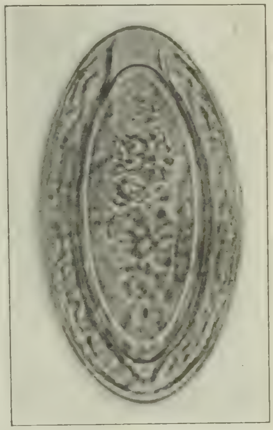

FIG. 256.—Photomicrograph of embryonated egg of *Macracanthorhynchus hirudinaceus*. × 500. (Original.)

In porcine hosts the attachment of the proboscis to the intestinal wall causes a localized area of inflammation, with infiltration of large numbers of eosinophiles and eventual necrosis of the region. Perforation of the intestine is not uncommon.

ORDER ECHINORHYNCHATA NOM. NOV.

Members of this order are characterized by having a well-developed proboscis. In most species the proboscis-sheath is composed of a double-layered almost cylindrical sac-shaped wall, into which the proboscis can be retracted. The prostatic glands consist of more than a single syncitial mass. The nuclei of the subcuticula and the lemnisci are relatively small and numerous, or, if few, of a dendritic nature. This order includes five families, of which the species of the family **Rhadinorhynchidæ** Travassos, 1923 have proboscides with stronger spines on the ventral side than on the dorsum; those of the family **Centrorhynchidæ** Van Cleave, 1916, have spines on the "neck" region; and those of the family **Corynosomidæ** Southwell and Macfie, 1925, have the anterior region of the body proper, at least in the males, clothed with cuticular spines. The family **Echinorhynchidæ** Cobbold, 1879 is a residual group, probably not a natural one. The

family **Moniliformidæ** Van Cleave, 1924, which is the remaining family, contains one species which is an occasional human parasite.

Family MONILIFORMIDÆ Van Cleave, 1924.

Echinorhynchate forms which as adults are parasitic in mammals, chiefly rodents. Except for the posterior extremity the body is usually divided into a large number of pseudo-segments, which frequently give the appearance of a string of beads. The proboscis-sheath is sac-like and has a wall composed of two muscular layers, of which the outer one consists of diagonally wound bands. The proboscis hooks are small, sickle-shaped, and have only a single, posteriorly directed, root-process, which is not sharply delimited from the hook. The family contains only one genus, *Moniliformis* Travassos, 1915, which has the characters of the family. This genus is further distinguished by having long, cylindrical lemnisci, with numerous large nuclei, by having the genital organs of the male restricted to the posterior extremity of the body cavity, and by the arrangement in pairs of the eight rounded cement glands of the female.

GENUS MONILIFORMIS TRAVASSOS, 1915.
(genus from *monile,* chain and *forma,* form).

Moniliformis moniliformis (Bremser, 1811) Travassos, 1915.

Synonyms.—*Echinorhynchus moniliformis* Bremser, 1811; *Gigantorhynchus moniliformis* (Bremser, 1811) Railliet, 1893; *Hormorhynchus moniliformis* (Bremser, 1811) Ward, 1917; *Echinorhynchus cestodiformis* v. Linstow, 1904; *Gigantorhynchus cestodiformis* (v. Linstow, 1904) Porta, 1908; *Moniliformis cestodiformis* (v. Linstow, 1904) Travassos, 1917.

The moniliform thorny-headed worm is whitish or creamy-white in color, and attenuated at both extremities (Fig. 257). The body is superficially made up of a series of bead-like pseudo-segments, which resemble the *Porocephalus moniliformis* (**Linguatulida**). The cylindrical proboscis (Fig. 258) has a length of 0.425 to 0.6 mm., and a diameter of 0.15 to 0.21 mm., and is armed with twelve to fifteen rows of recurved hooks, seven to eight hooks per row, each hook being continuous with a single posteriorly directed root-process. The males have a length measurement of 4 to 5 cm., and are characterized by a posterior campanulate bursa copulatrix which is visible to the naked eye. Each of the two testes is about 2 mm. long. The females have a length measurement of 10 to 27 cm. The cement glands are in the posterior extremity of the body and measure about 1.5 mm. in length. The eggs (Fig. 259) are ellipsoidal, measure 85 to 118 by 40 to 52 μ and are provided with the characteristic three envelopes. The embryos are striated and are covered

with spines. The intermediate hosts are species of beetles and cockroaches (*Blaps mucronata* in Europe, *Periplanata americana* in S. America) and possibly other insects. In these hosts the embryos

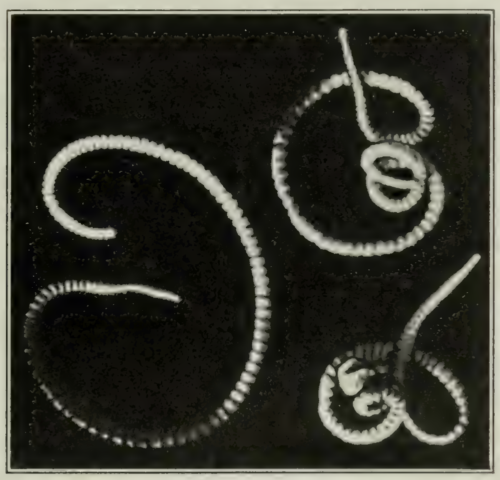

FIG. 257.—Photograph of *Moniliformis moniliformis*. Natural size. (After Travassos, in Reviste Vet. e Zoötechnica, 1920.)

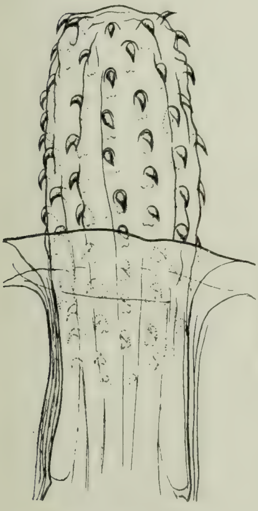

FIG. 258

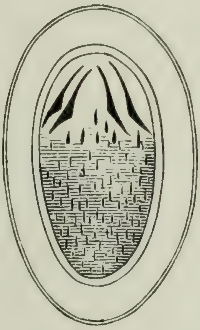

FIG. 259

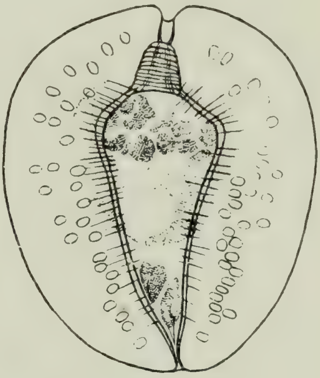

FIG. 260

FIG. 258.—Proboscis of *Moniliformis moniliformis*. × 100. (After Van Cleave, Proc. Acad. Nat. Sci., Philadelphia.)

FIG. 259.—Egg of *Moniliformis moniliformis*. × 500. (After Grassi and Calandruccio.)

FIG. 260.—Mature larva of *Moniliformis moniliformis*. Greatly enlarged. (After Travassos, in Reviste Vet. e Zoötechnica, 1920.)

develop into mature oval larva enclosed in a cystic capsule (Fig. 260). Infection of the mammalian definitive host results from ingestion of the infected larval host. The common hosts of the adult worms are species of rodents (*Mus norvegicus, M. rattus, M. alexandrinus, Microtus arvicola, Cricetus cricetus, Cricetomys gambianus,* etc.). Human infections, apparently well authenticated, have been reported from Italy (1 case of natural infection, also 1 of experimental infection), the Sudan (1 case from Khartoum) and British Honduras (1 case). Related species, *M. clarki* and *M. erinacei,* have been described respectively from squirrels (*Sciurus niger* and *Citellus 13-lineatus*) and from hedgehogs (*Erinaceus europæus*).

The experimental infection of Calandruccio (1888) demonstrated clearly that this species, when present in considerable numbers, produces definite symptoms. Nineteen days after ingesting several larvæ, Calandruccio was attacked with severe gastro-intestinal pain and diarrhea, accompanied by exhaustion, somnolence and a pronounced ringing of the ears. The period of complete incubation in man (*e. g.,* until eggs of the worm appeared in the feces) was about five weeks. Administration of *filix-mas* removed all of the worms within three hours, but the symptoms did not disappear for two days following treatment.

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SECTION IV.

HELMINTHOLOGY AND THE DIAGNOSTIC LABORATORY.

CHAPTER XXXI.

THE EQUIPMENT REQUIRED FOR THE DIAGNOSIS OF HELMINTHIC INFECTIONS.

Introduction.—Most laboratories in which diagnosis is made for helminthic infections are also expected to carry out parallel diagnosis in bacteriology, serology, urology, hematology and protozoölogy, and some clinical laboratories are also equipped for pathological diagnosis. Hence much of the equipment which is suggested in the following pages may be equally serviceable in other lines of clinical diagnosis. However, there are certain sets of apparatus and methods of technique which have been particularly developed to facilitate helminthological diagnosis and without which no all-round laboratory can be developed.

Microscopic Equipment.—It is desirable to have at least one compound microscope and one binocular dissecting microscope. The compound microscope may be any one of several serviceable models which are on the market. It should be compact and capable of hard usage. The fine-adjustment screw should be in a position so that the delicate tension is not strained when the microscope is lifted by the handle. There must be at least three objectives, (1) a low-power lens of about 16 mm. working distance, (2) a high-power dry lens of about 4 mm. working distance, and (3) a high-power lens of about 1.9 to 2 mm. working distance for use with immersion oil. It is advisable to have at least two oculars, a medium and a low power. For constant microscopic examinations a binocular mono-objective compound microscope is preferable, since it gives depth to the field and relieves eye-strain occasioned by the continued use of only one eye. The most modern microscope for the investigator is provided with monocular and binocular tubes which may be interchanged without changing the objective nose-piece and without altering the focus on a given preparation. The advantage

of such an arrangement is obvious: the specimen may be examined under binocular conditions, while photomicrographs and camera lucida drawings may be made under the monocular on a moment's notice. For the monocular-tube compensating oculars are best; for the binocular tube periplanatic lenses are the most serviceable. The objectives in the best microscopes have either apochromatic or fluorite lenses. The dissecting microscope should be equipped with two or three graded pairs of periplanatic oculars and two or three graded pairs of objectives. In case no dissecting microscope is available a lower magnification and greater working distance of the compound microscope may be obtained by unscrewing the lower portion of the low-power objective, leaving only a single lens for the objective. It must be remembered, however, that the dissecting microscope gives a direct image while the compound microscope gives an inverted one.

Microscopic equipment will only give satisfactory service if it is properly cared for. The lenses should be cleaned only with soft lens paper. Cedar oil should not be allowed to dry on the immersion objective but should be cleaned off with a minimal amount of xylol, care being taken not to leave any xylol on the lens lest it dissolve the cement in which the lens is mounted. The entire microscope should be protected as much as possible from dust and dirt as well as from moisture. The former is a particularly necessary precaution in city laboratories and in those where dust is prevalent; the latter, in humid climates especially near the sea coast. The bright metalled parts should be covered with a thin film of oil and the rack-and-pinion as well as the fine adjustment should be periodically lubricated with vaseline. When not in use it is desirable to keep the instrument covered with a tightly-fitting bell jar and out of direct sunlight.

In order to guarantee maximum efficiency, the compound microscope should be provided with a mechanical stage having a Vernier computator. This instrument should also be kept lubricated.

Differential diagnosis often requires micro-measurements. The micro-unit is the *micrometer*, usually designated by the Greek letter μ. This unit is 0.001 of a millimeter.

Measurements are made by placing a circular piece of glass, the ocular "micrometer" piece, on which accurate rulings are etched, on the support within the eye-piece of the microscope. When in position this micrometer eye-piece should be in clear focus and the scale should be right side up. Calibration of the micrometer eye-piece is made by the use of an object "micrometer," which is a slide on which there are usually engraved 100 units, exactly 10 μ apart, thus making a total length of 1 mm. The object "micrometer," which is the absolute gauge, is placed in the center of the microscopic field under the low-power lens, so that it is in clear focus, and

so that the ocular "micrometer" is superimposed on it in equally clear focus. Readings are then made of the number of object-"micrometer" units which are exactly equal to a given number of ocular-"micrometer" units. Thus, if one ocular unit exactly coincides with one object unit, the value of the ocular unit is 10 μ; if 20 ocular units equal 16 object units, the value of the 20 ocular units is 16 by 10 μ or 160 μ and the value of each ocular unit is 8 μ. Similar calibrations should be made for the high-power dry objective and for the oil-immersion objective in combination with the same ocular, and similar computations should also be made for any other ocular to be used in combination with these objectives. It is usually advisable that these measurements be made with the microscope tube entirely down or drawn out to a fixed point (as, for example, 152 mm.). If the latter tube-length is used then it is necessary that the tube be set at this particular length in all subsequent measurements made. The unit values thus secured apply only to the particular combination of lenses for the particular microscope calibrated, with the tube drawn to the particular length used. Most microscopes of the same make or type have approximately the same absolute magnification for the same lens combinations but no two are likely to give exactly the same readings. Once obtained, the unit-values for the microscope to be used should be recorded in tabular form in a convenient place. When measurements of microscopic objects are to be made the values are taken in terms of ocular units and converted into microns by reference to this table.

It is frequently desirable to make exact tracings of objects under the microscope. This is done by the use of a *camera lucida* attached to the upper end of the microscope tube immediately surrounding the ocular. The camera lucida is an instrument consisting of a silvered prism, a graduated horizontal arm and a mirror, with accessory pieces for adjusting the light and centering the object. The instrument is clipped over the empty microscope tube, the ocular inserted, the mirror set at 45 degrees and the light and center adjusted. Under these conditions the image of the pencil point immediately under the mirror is reflected back into the microscope, so that the eye sees at one and the same time both the specimen to be sketched and the pencil point. The specimen may then be traced on a piece of white paper under the pencil point. It is convenient that the paper rest on a small drawing table which has the same elevation as the microscope stage. In order not to distort the image sketched it is necessary (1) that the mirror be set at exactly 45 degrees; and (2) that the horizontal distance from the center of the silvered prism to the mirror be the same as the vertical distance from the mirror to the drawing table. Adjustments may be made by drawing out the microscope tube to the desired point. The

actual magnification of the tracings made may be determined by removing the specimen from under the microscope, substituting the object "micrometer" slide and tracing its 10 μ unit lines on the drawing paper.

Theoretically the best light for the microscope is clear white sky-light. Direct sun's rays are disastrous to consistent microscopic examination. Practically, a more uniform light is obtained from an incandescent electric light of 100-watt capacity or an equally strong mantled gas lamp, the rays being filtered through a frosted "day-light" blue glass plate. Frequently the use of the higher powers of the binocular compound microscope requires more intense illumination than sky-light admits, so that many clinical microscopists using this equipment have come to rely entirely on a uniform filtered electric lamp.

Glassware Required.—In addition to the regulation glassware supply of the clinical laboratory, such as an abundance of hard-glass and medium-soft-glass test-tubes, centrifuge tubes, serological tubes, petri dishes in graduated sizes, graduated pipettes, etc., the following glassware supply is of special use in the helminthology laboratory: (1) microscopic slides and cover-glasses; (2) staining dishes; (3) ribbed filter funnels; and (4) vials, bottles, museum jars and aquaria.

1. **Microscopic Slides and Cover-glasses.**—Two sizes of microscopic slides are required, the usual size (25 by 75 mm.) and a larger size (40 by 75 mm.). The former is used for blood-films, permanent fecal smears, ordinary sections and *toto* mounts; the latter, for preliminary fecal smears and fecal concentration films and unusually large sections. The cover-glasses should consist of a supply of 24 mm. squares, a smaller number of 50 by 24 mm. size and occasionally a larger size to cover serial sections. Both slides and cover-glasses should be of a clear white consistency, without bubbles or streaks and should not be cloudy or etched. The slides should be of uniform medium thickness with slightly beveled, clean-cut edges, so that blood-films can be easily streaked across the slide. The cover-glasses should be sufficiently thin (18 μ or less) to accommodate an oil-immersion lens when fairly thick fecal films are being examined.

2. **Staining Dishes.**—These dishes are made in a variety of sizes and shapes. The most satisfactory ones have ribbed partitions and accommodate from 20 to 24 ordinary slides placed back to back. A staining set consists of about a dozen such jars.

3. **Ribbed Filter Funnels.**—These funnels are for special use with the Baermann apparatus (see p. 532). Eight to twelve with a flange diameter of 15 to 25 centimeters are required for a set.

4. **Vials, Bottles, Museum Jars and Aquaria.**—A supply of graduated sizes of homeo and shell vials, wash-bottles, museum jars and glass aquaria is desirable for the temporary and permanent storage of

helminth specimens and tissues. The emphasis placed on this phase of the work will determine the amount of this stock to be provided.

Cleaning of Glassware.—In order to prevent *laboratory glassware* from becoming etched or cloudy it *should never be cleaned in strong soapy water.* Unused glassware can frequently be conditioned by placing it in a 2 per cent solution of nitric acid, then rinsed thoroughly in water and dried with a clean linen towel. Used or dirty glassware is ordinarily cleaned by being immersed in the following solution:

Concentrated H_2SO_4	6 parts
$K_2Cr_2O_7$	6 parts
Water	100 parts

After soaking in this mixture the articles are thoroughly rinsed in water and dried with a non-linty cloth.

Slides and cover-glasses require special care. They may either be cleaned in the above mixture or in concentrated nitric acid, rinsed thoroughly in distilled water, then passed through absolute ethyl or methyl alcohol, and dried with a fine linen towel or piece of old linen sheeting. It is frequently advisable to keep slides and cover-glasses in absolute alcohol in dishes with a vaselined rim, and dry them only as they are needed. The greatest care should be taken to prevent slides and cover-glasses, as well as the other laboratory glassware from coming in contact with the fumes of strong acid and alkalies.

Other Equipment.—Standard incubators are needed for culture work and a low-speed centrifuge is required for concentration of ova. Paraffin baths are desirable for imbedding specimens to be sectioned. A standard sliding microtome with a supply of knives is required for sectioning of tissues. A plentiful supply of specimen applicators (long tooth-picks about 5 inches in length) is needed for mixing and streaking fecal smears.

Chemicals.—The helminthology laboratory should be provided with the ordinary reagents and other chemicals and, in addition, an adequate stock of stains. All of these are usually on the shelves of a well-equipped clinical laboratory. The salt used for concentration of helminth ova (see p. 528) is ordinary commercial sodium chloride, which is made up as a concentrated solution, filtered and kept in a stoppered bottle. There should be large stock bottles of distilled water, physiological salt solution, citrated salt solution, Buffer solution (see p. 503), 95 per cent ethyl alcohol, 10 per cent formalin (*e. g.*, 4 per cent CH_2O), 5 per cent formalin, $\frac{N}{10}$ NaOH solution for egg counts (see p. 530), and smaller bottles of the various concentrations of ethyl alcohol (15, 35, 50, 70, 85, 95 and 100 per cent in distilled water).

CHAPTER XXXII.

THE COLLECTION, PREPARATION, AND PRESERVATION OF HELMINTHOLOGICAL MATERIAL.

The most important point to be emphasized about helminthological specimens is that, wherever possible, they should be collected and studied in the living state. No small part of the inaccuracies and incompleteness in the description of helminths has been due to the study of poorly-fixed or preserved material. In general, there are two sources of human helminthological material, the clinic and the field. A laboratory of helminthology which is divorced from either of these two sources of supply is greatly handicapped. The clinic provides material from human sources; the field provides material from reservoir and intermediate hosts as well as from the human population.

Frequently it is neither possible nor desirable for the clinician or the epidemiologist to follow a helminthological problem to its conclusion. Specialists may be required to investigate certain conditions or certain phases of the life cycle of an organism, or to identify helminth parasites or their natural hosts. To secure optimum results under such conditions the following requirements must be met. (1) The clinician or field investigator must have an intelligent understanding of the problem, obtained by special study of the subject in a laboratory where medical helminthology is taught. (2) He should understand his own limitations in the strictly helminthological aspects of the problem and invite coöperation. He should not be afraid of calling for expert opinion. (3) He should obtain adequate first-hand case histories or field notes which will provide the proper background for the coöperative study. Where the technical expert resides at some distance from the source of material, he must depend for accurate clinical and biological information obtained at the time the material was collected. It would almost be better that specimens be not collected and preserved than that they be poorly treated or accompanied by inadequate notes.

I. The Study of Fresh Material.—This requires an appreciation of the possible bearing of such study on the future development of the subject. It may be that such study is afforded only once in a life-time or at most only infrequently. Accurate measured drawings (preferably with the camera lucida) with full notes should be

made, so as to indicate the size, shape and variation of the material, important external features of the living specimens, sexual differences, if such obtain, and internal organization in so far as it can be made out. The material should be studied in as natural a medium as possible, since hypertonic or hypotonic media are usually harmful to any organism. It is particularly important that the flame-cell pattern of trematodes be studied in living material. This can only be done when the specimen is flattened out under a cover-glass and is moderately free of cystogenous-gland inclusions. Frequently the solenocytes (*e. g.*, flame-cells) themselves can be observed only a few minutes before the body structure breaks down. It is also important that nematode larvæ be studied while still alive in order to observe their characteristic movements. Vital-staining reactions (see p. 502) of microfilariæ are frequently very significant in determining the landmarks and in differentiating closely related species.

In all of these preliminary observations it is essential to record whether the material was obtained from spontaneous evacuation, after therapeusis, from biopsy with or without anesthesia or at necropsy; the number of the specimens obtained; their condition, whether alive, moribund or dead, and wherever possible the host's tissue or organs in which they were found; likewise the pathological and clinical complications which might be directly or indirectly attributed to the parasite. Care must be taken, however, not to infer causal relationships of organisms to diseased conditions which cannot be proved or which are very unlikely. If the helminth is known to be a parasite of other hosts its percentage incidence in such hosts as well as in man should be noted. Moreover, any physical, biological or economic conditions which might have a bearing on the establishment or perpetuation of the infection should be recorded.

II. Fixation of Material.—It is convenient to consider this phase of the subject under the following subtopics: (1) blood-films; (2) adult worms and larvæ; (3) helminth eggs; (4) pathological tissues; and (5) intermediate and reservoir hosts. The methods utilized in each case are at least partly dependent on the use which is to be made of the specimen, whether for general morphological, cytological or exhibit purposes.

1. **Blood-films.**—Blood films are made for microfilariæ and trichinella larvæ, as well as to determine the relative number of leukocytes in a given infection. For Romanowsky stains such as Wright's or Leishman's, careful drying of the film before staining is sufficient. For Giemsa technique fixation in absolute methyl alcohol is a prerequisite. If some time is to elapse before staining with either of these methods, fixation in methyl alcohol is indicated. For thick-drop preparations (Fig. 261) and ordinary films requiring dehemaglobinization the film should first be air-dried, then dehemaglobinized in distilled water, and air-dried again, before fixation in

methyl alcohol. Such films may remain unstained for months and will later stain beautifully. Special fixation in a concentrated aqueous solution of mercuric chloride is advised for permanent hematoxylin-stained preparations (see p. 503).

2. **Adult Worms and Larvæ.**—If the material has been secured in the living condition from the host it should be thoroughly shaken in physiological saline solution prior to fixation, in order to secure proper relaxation. For rapid preservation which is both simple

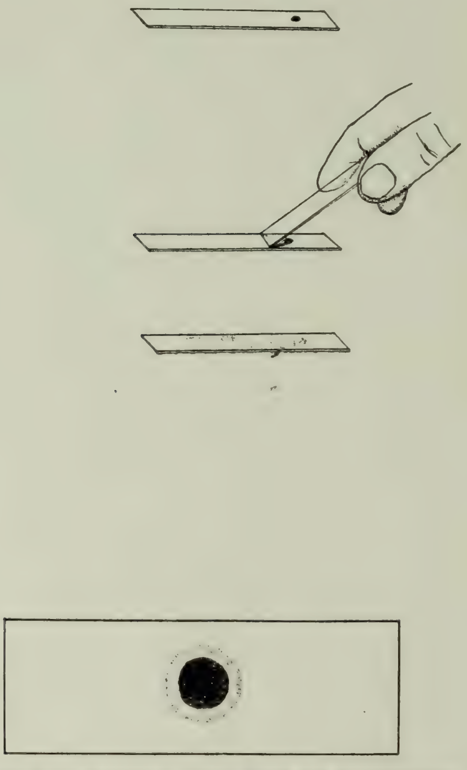

Fig. 261.—Methods of preparing blood-films for examination. Above, making a thin blood-film; below, appearance of a properly prepared thick-blood smears, dried and ready for dehemaglobinization. (Original.)

and fairly satisfactory for gross structures the specimens may be fixed in steaming (not boiling) 5 per cent formalin (2 per cent CH_2O), the fixing fluid being poured into the medium containing the worms, which are meanwhile kept constantly agitated to prevent contraction. The material may be left permanently in this medium or may be transferred after washing in water through 35 per cent and 50 per cent to 70 per cent alcohol. For better histological details a steaming mixture of corrosive sublimate and acetic acid (saturated

solution $HgCl_2$ in physiological medium, to which a few drops of glacial acetic acid have been added) is used. After ten to twenty-four hours the specimens are carefully washed, and transferred by degrees to 70 per cent alcohol, at which time alcoholic-iodine-solution should be added drop by drop to remove the mercuric chloride, until the alcohol remains tinged a slight sherry color. After twenty-four hours the material may then be transferred to pure 70 per cent alcohol. For nematodes, particularly those with a resistant cuticula, better results can sometimes be obtained by fixing the specimens in steaming 70 per cent alcohol to which a few drops of glacial acetic acid have been added. After a few hours they should be transferred to acid-free 70 per cent alcohol plus 5 per cent glycerin. Small nematodes may be relaxed in chloroform water and killed by heating. A medium of carbol-lactic acid is recommended by some workers for preservation of nematodes. Others advise the gradual transfer to a glycerin medium in order to render the worms more transparent. For delicate histological details Bouin's or Flemming's fixatives are perhaps the most satisfactory. For gravid segments of tapeworms, the injection of the uterus with India ink, after inserting the needle of the syringe into the vagina, previous to fixation of the segment, affords a striking contrast between the uterus and the mesenchyma of the segment.

3. **Helminth Eggs.**—Feces containing helminth eggs may be treated with an equal amount of hot 10 per cent formalin (4 per cent CH_2O). After fixation the material should be gradually transferred to 70 per cent alcohol for preservation, since the outer coatings of many eggs break down in prolonged formalin preservation. Cold formalin frequently fails to kill the embryos inside resistant egg-shells, so that they continue to develop. Direct alcoholic fixation causes shrinkage of the more delicate egg-shells. For cytological work, Bouin's and Fleming's technique should be used.

4. **Pathological Tissues.**—For gross pathological structure material may be fixed in 10 per cent formalin. For histological study Zenker's fluid is preferred ($K_2Cr_2O_7$, 2.5 gm., and $HgCl_2$, 5 gm., in 100 cc. water, to which there is added just before using, 5 cc. of glacial acetic acid). For museum or gross demonstrations Kaiserling's solutions I and II may be used. If the tissue is likely to shrink or curl it should be spread out on a thick piece of white cardboard and placed up-side-down in the fixative. For clarification large objects may be transferred through dehydrating agents into paraffin oil or tetralin.

5. **Intermediate and Reservoir Hosts.**—Aquatic arthropods, mollusca, fishes, frogs and snakes may be fixed and preserved in 70 per cent alcohol. If these animals are infected and it is desired to preserve the helminths as well as the hosts, some one of the techniques under (2) above should be employed for the fixation of the

parasites. Large vertebrates should either be eviscerated or should at least have the visceral cavities opened before fixation. Many land or aërial arthropods may be preserved as dry specimens. This method is to be preferred for Diptera, which should be pinned and mounted according to methods approved by entomologists. If gasteropod shells are to be preserved dry, care must be taken that the radula within the mouth cavity and the operculum (if present) are not lost or destroyed. In the case of birds and mammals, usually the pelts, with the skull and the legs (attached), are saved and the viscera, muscles and remaining skeleton discarded. If the latter tissues are suspected of containing parasites they should be examined in the field laboratory, the infested portions and helminths properly fixed and the offal discarded. Pelts are preferably dried or treated with arsenical ointment but may be fixed with salt or quicklime and in some cases with arsenious oxide.

In all cases it is essential that the specimens be properly and adequately labelled as to habitat, host and other details. Specimens preserved in glass containers should have a water-proof label inside the container. Usually a pencilled label on tough paper is satisfactory. Labels on the outside of glass bottles are apt to get separated from the specimen which then becomes nameless. Mounted insects should have the label pinned to the mounting board. Pelts and skulls should have strong tags attached.

III. Staining and Mounting Methods.—It is obviously impossible to give all of the various staining techniques which have been utilized for the study of helminth parasites. In the limited space available a few of the more useful procedures will be described for each type of preparation.

1. **Blood-films.**—These are prepared for the diagnosis and study of microfilariæ and trichinella larvæ.

(*a*) *Vital Staining.*—Thin drops of blood from venipuncture of the finger or ear are mounted with a cover-glass and ringed with vaseline, previous to which a drop of methylene blue solution (1 to 5000 in physiological saline) is drawn under the cover-glass. The microfilariæ of *Wuchereria bancrofti, Loa loa, Onchocerca volvulus, Acanthocheilonema perstans* and other species can readily be differentiated with this technique. Thus Sharp has found that the living *Mf. bancrofti* and *Mf. streptocerca* are practically indifferent to the dye, while those of *Loa loa* and *O. volvulus* absorb it with avidity, and those of *Mf. perstans* have an even more powerful affinity for the dye. Moreover, the internal landmarks are quite clearly stained in the latter three species. In case the larvæ in the peripheal circulation are too few to appear in a thin film, as much as 5 or 10 cc. of blood is obtained from the patient, dehemaglobinized in water then centrifuged and the sediment mounted with methylene blue and examined.

(*b*) *Permanent Films.*—If the larvæ in the peripheral blood are abundant, thin films may be used; if they are scarce, thick drops should be secured. These are placed on the slide and air dried as rapidly as possible; then hemaglobinized, air dried again, and fixed in methyl alcohol, when they are ready to stain. Wright's or Leishman's stains are usually less satisfactory than Giemsa's. In using the latter technique dilute the stock solution 1 minim to 1 cc. of distilled water and place the slides in the dilute stain for one-half hour or more until the desired amount of staining has been obtained. The body of the larva, with the excretory and genital cells is stained azure, the excretory pore and the anal pore are deep eosinophile and the "sheath" if present is tinted a delicate pink. If the stained film has a precipitate of the azure-eosinate, this may be removed by washing in acetone. For more distinct staining of the "sheath" hematoxylin dyes should be used. Fülleborn recommends Bohmer's hematoxylin for this purpose. (Solutions: (A) 1 gm. hematoxylin crystals and 12 cc. absolute alcohol; (B) alum 1 gm. and distilled water 240 cc. Add 2 or 3 drops of (A) to a watch-glassful of (B)). The dry dehemaglobinized smears are covered with the solution, heated until slightly steaming, rinsed off with distilled water, differentiated with acid alcohol (2 per cent HCl in 70 per cent alcohol), rinsed in dilute ammonia water (1 to 10,000), rapidly run up through the alcohols, cleared in xylol and mounted in euparal.

In delicate blood-film work difficulty is frequently experienced because of the variable pH of the distilled water. Under such circumstances it is desirable to substitute a buffer solution for the distilled water. The author has found the following buffer solution distinctly valuable for overcoming this difficulty with blood-films: (1) pure recrystallized acid potassium phosphate, 13.26 gm.; (2) anhydrous dibasic sodium phosphate, 5.12 gm.; (3) distilled water, 2 liters.

2. **Adult Worms, Larvæ and Eggs.**—(*a*) *Vital Staining.*—Very little has been done in the adaptation of vital-staining methods to the study of the structures of adult worms or larvæ not recovered from the blood. Faust and Meleney (1924) have successfully utilized dilute solutions of neutral red and cresyl blue in working with free-swimming trematode miracidia. A similar technique can be applied to the study of the free-swimming ciliated hexacanth embryo of pseudophyllidean cestodes.

(*b*) *Permanent Preparations.*—For careful examination and differentiation of most helminths both *toto* mounts and specimens should be prepared. In the case of some of the more delicate larvæ *toto* mounts are sufficient; on the other hand, some specimens are too large or too bulky to prepare as *toto* mounts. Trematodes in all stages of development should be treated in both ways. The strobila of the smaller cestodes, such as *Hymenolepis nana,* may be mounted

as a whole, but for most tapeworms it is desirable to select segments from typical regions for both *toto* and section work. Most nematodes may be handled in both ways. Gordiacea and Acanthocephala are extremely difficult to manipulate and should only be prepared by specialists.

I. *Toto Mounts.*—Two types of staining are recommended, using carmine and hematoxylin dyes. The former is better for small objects since its power of penetration is relatively slight. It is a general protoplasmic stain. The hematoxylins are most satisfactory for larger objects and particularly for the genital organs of helminths, which are stained with different degrees of intensity and in different shades. Grenacher's alum-carmine and Mayer's carmalum are the carmine stains that perhaps yield most uniform results. The solutions are used without dilution, and the preparations are afterward washed with water. If the material has been overstained weak acid may be used to destain. Specimens should not have an acid reaction if it is desired to employ carmine stains.

Delafield's and other hematoxylin stock solutions should be diluted at least with 10 parts of water before using, since they are very active penetrating dyes. The length of time required for *toto* objects varies with the size of the object and with the dilution of the ripened stain. In any event it is usually desirable to overstain and then to destain with 0.5 per cent HCl in 70 per cent alcohol, until the excess has been removed and the material is a rather light reddish mahogany. It should then be thoroughly washed in distilled water and transferred to a weakly alkaline medium. The most delicate differentiation with the development of various lavender and violet hues can be obtained by using a 1 per cent lithium carbonate in distilled water. Ehrlich's acid hematoxylin, which is less likely to overstain, is preferred by some stain technologists for *toto* preparations. On the whole, the author has had more success with Delafield's solution.

The specimens which have once been properly stained, differentially destained and then neutralized, should be passed through successive grades of alcohol (35, 50, 70, 85, 95 and 100 per cent), cleared and transferred to a mounting medium. The length of time required in the alcohols depends in part on the fixation, in part on the size of the specimen, and in part on the permeability of its integument. No arbitrary rule can be followed on this point; the student must test out each group of specimens with respect to its special needs. In general, however, nematodes should be handled very slowly, since their integument, no matter how thin, is easily shrunken by rapid dehydration. The specially modified Cobb technique devised by Svensson and Kessel, is recommended for small nematodes and for all helminth ova. The material, killed in 50 per cent or 70 per cent steaming alcohol is treated as follows:

1. A circular piece of fine-meshed linen or silk cloth, which is equipped with one linen thread through the center and another thread basted in and out around the edge with both ends free (Fig. 262, *1*), is placed in a small funnel glass, and the material strained through the funnel, so that the specimens are caught on the cloth (Fig. 262, *2*). The latter is then drawn into the form of a little bag by tightening the marginal string, and is inserted into a small object holder, consisting of a piece of glass tubing 10 mm. in diameter by

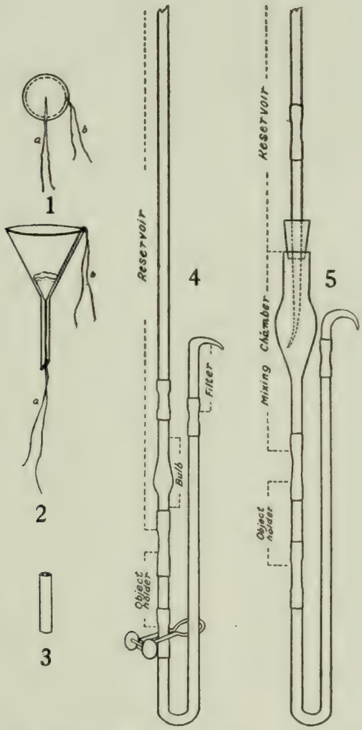

FIG. 262.—Apparatus for staining and clearing small nematode larvæ. (From Svensson and Kessel, in Jour. Parasitology.)

4 cm. in length (Fig. 262, *3*). The object holder is then placed for two hours in a test-tube containing the following fixing fluid: (1) acetic acid, 1 part; (2) 95 per cent alcohol, 1 part; and (3) saturated aqueous solution of mercuric chloride, 1 part. The object holder is then placed in position in a staining apparatus (Fig. 262, *4*), and filled with 35 per cent alcohol which is colored with tincture of iodine to a dark amber hue. The clamp is so regulated that about 30 cc. of the fluid passes through the object holder in twelve hours. Following this distilled water is passed through the apparatus for about

an hour. The apparatus is next filled with Delafield's hematoxylin (1 to 25 dilution) and left for twenty-four hours. Following the staining, water is again passed through for twenty minutes; then 5 per cent acetic acid for five minutes followed by distilled water; then 5 per cent ammonia water for five minutes and a final run of distilled water. The object-holder is then transferred to Magath's differentiator (Fig. 262, *5*), and the reservoir successively filled with 35, 50, 70, 85 and 95 per cent and absolute alcohol, 50 cc. of the latter being run through in twenty-four hours. The object holder is then removed to a stender dish filled with absolute alcohol, which is connected by wicks with two other stenders, one slightly higher and one somewhat lower than the first. The uppermost dish is filled with equal parts of absolute alcohol and methyl salicylate and the liquid allowed to pass down through the object holder; when finally drained out of the uppermost dish a supply of pure methyl salicylate is passed through the object holder, until the specimens are bathed in pure methyl salicylate. The bag is then removed from the object holder and the specimens mounted on a slide in a drop of damar in methyl salicylate.

Clarification of dehydrated objects may be effected by the use of xylol, cedar or clove oil or methyl salicylate. The last named is the one of choice for *toto* preparations, since it has a high refractive index, renders objects least brittle and shows least emulsion when moisture is accidentally included. On the other hand carbol-xylol and tetralin are slightly better for the rapid penetration through hardened and less permeable tissues. The mounting medium should be neutral. Canada balsam and dammar dissolved in xylol are most commonly employed but they frequently require neutralization. This may be accomplished by placing a few small chips of pure marble ($CaCO_3$) in the stock bottle and letting the reaction take place over a period of months.

II. *Sections.*—For sectioning of helminth parasites the worms should first be stained with hematoxylin before imbedding, in order that the objects may easily be seen. Imbedding and sectioning techniques for helminths do not differ essentially from those for other zoölogical or pathological specimens. They require dehydration through successive grades of alcohol, clearing in xylol and gradual transfer to hard paraffin, or the transfer through ether-alcohol into celloidin. Paraffin sections are entirely satisfactory for most helminths but for those containing large heavy-shelled eggs the celloidin technique is preferred. For detailed study it is desirable to have serial sections through the entire worm. Sections in both the transverse and frontal or sagittal planes are usually called for if the material is available. For ordinary examination the sections may be cut 8 to 10 μ in thickness. The ribbons of paraffin coming from the cutting block, after being smoothed out by floating on warm water are fixed to the slide in series (the slide having first

been covered with a very thin film of egg-albumin fixative), dried and the paraffin dissolved in xylol; or if the sections are celloidin, they are placed in series on the slide, fixed to the slide by a thin film of collodion, and hardened.

The staining of the slides follows the hematoxylin-eosin technique. At times, however, it is desirable to counterstain larval trematodes (*e. g.*, miracidia or cercaria) with ammonium-carmine after the method of Best for glycogen, in order to study the specific reaction of secretory glands. For such technique material fixed in mercuric chloride, alcohol or formalin is suitable, since the secretory granules of these glands are not dissolved as is glycogen by a fixing agent containing water. Except in very delicate cytological work iron-alum hematoxylin staining of sections of helminths is neither necessary nor advisable.

3. **Host Tissues Containing Helminths.**—The material is treated similarly to that employed for sections of helminths. (See above.) In case molluscs are to be sectioned in part or in whole, the calcareous shell should first be removed. Sand grains in the intestine of this animal frequently cause serious difficulty in making satisfactory sections. Calcareous granules and concretions may be removed by previously immersing the tissue in a weak solution (0.5 per cent) of hydrochloric acid for some days, thoroughly washing and neutralizing.

CHAPTER XXXIII.

THE IDENTIFICATION AND DIFFERENTIAL DIAGNOSIS OF HELMINTH PARASITES AND THEIR EGGS.

Introduction.—The equipment for a helminthological diagnosis laboratory and the methods of preparation of material for study, which have been described respectively in Chapters XXXI and XXXII of this section, are directed primarily toward one end, namely, the identification of helminth parasites and their eggs, in order that definite diagnoses may be made. Most of the information with regard to the adult worms, their eggs and the various larval stages in their life cycles has been given in detail in Sections II and III of this book, so that a careful study of these chapters will in most cases furnish adequate data for diagnostic purposes. It seems appropriate, however, to bring together in one place such information as is of specific diagnostic value in order that it may be more useful to the laboratory man. For this purpose methods of procedure in examining human excreta and body fluids for helminth eggs and larvæ are presented; summary tables and keys are provided for the more common helminths and their eggs; diagrammatic and photographic illustrations of the eggs have been prepared; artefacts, contaminators or other objects in the feces liable to be confused with helminth eggs are illustrated and described; various methods of concentration and of counting eggs and larvæ are discussed, and serological tests applicable to the diagnosis of helminth infections are presented.

1. EXAMINATION OF HUMAN EXCRETA AND BODY FLUIDS FOR HELMINTH EGGS AND LARVÆ.

(For necessary equipment see Chapter XXXI.)

(*a*) **Diagnostic Procedure for Eggs and Larvæ in Human Excreta.**—For convenience this topic is divided into three subtopics, each dealing with one of the three common types of human excreta, the urine, sputum and feces.

Urine.—In heavy infections either *Schistosoma hæmatobium* or *Dioctophyme* eggs can be readily recovered from the muco-purulent settlings after the urine has been allowed to stand for a few moments

in a urinalysis glass. A bit of the sediment is taken up in a capillary pipette, placed on a fecal slide and examined with or without a cover-glass under low power of the microscope. If the infection is light a representative specimen should be centrifuged at 1000 revolutions per minute and a bit of the sediment examined. Microfilariæ of *Wuchereria bancrofti* in chylous urine, or larvæ or adult rhabditid nematodes which are accidental residents of the urino-genital tract, as well as protozoa, if present, may be recovered from the urine by similar methods of concentration. Helminths or eggs passed in urine may be permanently preserved by the methods described in Chapter XXXII.

Sputum.—In patients suspected of having helminthic infections of the respiratory passages, the mouth is first thoroughly rinsed with hydrogen peroxide solution and the sputum then passed into a sputum-jar. A small portion is transferred to a fecal slide by use of a long tooth-pick or specimen applicator, mounted with a cover-glass and examined under the microscope. For temporary preservation sputum may be mixed with a weak solution of phenol.

Feces.—Preparation for simple routine examination of feces for helminth ova and larvæ consists in mixing a small fleck of uncontaminated specimen with a few drops of physiological saline, streaking a portion of the mixture evenly over the center of a fecal slide and mounting with a cover-glass (preferably 50 by 24 mm. in size). The careful examination of three such smear preparations from representative parts of the specimen will serve to discover practically any clinical helminthic infection in which the eggs are passed in the feces. Where intestinal schistosomiasis (due either to *Schistosoma mansoni* or *S. japonicum*) is suspected, the eggs are most likely to be recovered from flecks of blood or mucus in the feces. In light infections or in order to shorten the examiner's time the concentration methods discussed under Topic 5 of this chapter should be employed. It should be remembered that fecal smears must be thin enough to view clearly all of the objects under the cover-glass. Only experience will provide facility in determining which types of specimens must be streaked thin and which ones may be streaked somewhat thicker.

(*b*) **Diagnostic Procedure for Helminth Larvæ from Blood and Lymph.**—Thick blood-films may be prepared by the technique described in Chapter XXXII, or fresh blood may be defibrinized by vigorous shaking, then dehemaglobinized and centrifuged. Lymph or serous fluid to be examined may likewise be centrifuged. Nematode larvæ, if present, will be found in the bottom layer and can be drawn off with a pipette. *Trichinella* larvæ and *microfilariæ*, even when present in small numbers, may be recovered from these fluids by employing this method.

2. IDENTIFICATION OF ADULT WORMS AND LARVÆ IN ADVANCED STAGES OF DEVELOPMENT.

Adult helminths are most commonly found in the intestinal tract, although a considerable number of species is found in other localities, such as the biliary passages, lungs, portal circulation, lymphatics and subcutaneous tissues. Occasionally these worms are expelled spontaneously, but the larger number is recovered after administration of anthelminthics, on biopsy, or at necropsy. In the majority of cases diagnosis can be made from examination of the eggs of the parasite passed in the patient's exudates.

Diagnostic Key for the Identification of Helminths Recovered from Human Infections.

A. Adult Worms.

1 (56). Adult worms primarily located in the digestive tract. 2
2 (3). Free in the intestinal lumen . . . . Ascaridæ (pp. 406–418). (See also 41 and 42, this key.)
3 (2). Attached to or imbedded in the intestinal wall 4
4 (29). Worms hermaphroditic, flattened dorso-ventrally . . . 5
5 (18). Body composed of distinct regions, consisting of a head, at times a neck region, and of several to many segments making up a strobila; each segment containing a full complement of sexual organs. (Cestodes). 6
6 (7). Head more or less spatulate, with a pair of suctorial sulci or grooves; openings of genital organs all on the ventral side; uterus provided with a pore . . . . (Pseudophyllidean Cestodes). (See Chapter XVII.)
7 (6). Head tetrangular, provided with four symmetrically arranged suckers around an apical organ or rostellum; genital atrium lateral; uterus without a pore. (Cyclophyllidean Cestodes). 8
8 (9). Neck region absent . . . . *Bertiella satyri* (p. 263).
9 (8). Neck region present 10
10 (11). Genital organs double . . . . *Dipylidium caninum* (p. 265).
11 (10). Genital organs single 12
12 (13). Uterus broken up into egg capsules . . . . Davaineidæ (pp. 268–270).
13 (12). Uterus fundamentally sacculate 14

14 (13). Gravid segments broader than long; uterus persistently sacculate.....HYMENOLEPIDIDÆ (pp. 270–274).
15 (14). Gravid segments usually longer than broad; uterus developing lateral arms.............(TÆNIIDÆ). 16
16 (17). Scolex unarmed........*Tænia saginata, T. confusa, T. africana* (pp. 283, 288, 289).
17 (16). Scolex armed...............*Tænia solium* (p. 276).
18 (5). Body consisting of a single segment; with a circumoral and a median ventral or posterior acetabulum. (TREMATODES). 19
19 (22). Acetabulum terminal or subterminal............. 20
20 (21). Body flattened and divided into a cephalic and a caudal portion, the latter in the form of a ventral sucking disk.....*Gastrodiscoides hominis* (p. 159).
21 (20). Body not divided into two parts................. *Watsonius watsoni* (p. 157).
22 (19). Acetabulum in the equatorial or the pre-equatorial plane...................................... 23
23 (26). Large fleshy ovate worms...................... 24
24 (25). Testes and ovary highly branched; eggs in early stages of segmentation when oviposited......... *Fasciolopsis buski* (p. 169).
25 (24). Testes and ovary entire; eggs with fully-developed embryos when oviposited.................... *Isoparorchis trisimilitubis* (p. 224).
26 (23). Small to medium-sized worms, with testes and ovary rounded or slightly lobed...................... 27
27 (28). Head provided with a corona of large conspicuous hooks.............ECHINOSTOMATIDÆ (pp. 178–185).
28 (27). Head lacking conspicuous hooks; worms small; a specialized genital sucker present..HETEROPHYIDÆ (pp. 191–200).
29 (4). Worms fundamentally diecious, cylindrically shaped. 30
30 (33). Head provided with a proboscis; intestine absent. (ACANTHOCEPHALA). 31
31 (32). Proboscis reduced, body elongate-cylindrical, with cuticular wrinkling or pseudosegmentation....... *Macracanthorhynchus hirudinaceus* (p. 487).
32 (31). Proboscis well developed; body divided into moniliform pseudosegments........................ *Moniliformis moniliformis* (p. 490).
33 (30). Head lacking a proboscis; intestinal tract present... 34
34 (37). Esophagus consisting of a chitinous tubule running through the center of a row of cells............ (TRICHOSYRINGATE NEMATODES). 35

35 (36). Copulatory sheath and spicule lacking in male worms; females viviparous. . . . *Trichinella spiralis* (p. 323).

36 (35). Copulatory sheath and spicule present in male worms; females oviparous . . . . *Trichocephalus trichiurus* (p. 329).

37 (34). Esophagus muscular, with a tripartite lumen . . . . (MYOSYRINGATE NEMATODES). 38

38 (43). Heterogenetic forms; parasitic stages without separate males 39

39 (42). Esophagus with a posterior bulbus containing valves and frequently having a prebulbar swelling 40

40 (41). Adults (females) of parasitic stage entirely imbedded in intestinal wall . . . . *Strongyloides stercoralis* (p. 336).

41 (40). Adults only temporary lodgers in the intestinal tract. *Rhabditis* spp., *Turbatrix*, etc. (pp. 341–346).

42 (39). Pharynx modified into a protrusile spear; accidental migrants through the intestinal tract . . . . TYLENCHIDÆ (pp. 346–348).

43 (38). Monogenetic forms; both sexes present in the intestinal tract 44

44 (49). Males provided with a true bursa copulatrix supported by 6 pairs and one or two dorsal rays and with copulatory spicules 45

45 (48). Bursa of males broad, well developed; buccal capsule well developed 46

46 (47). Buccal capsule without teeth or cutting plates but having a ring of chitinous armature . . . . STRONGYLIDÆ (pp. 351–355).

47 (46). Buccal capsule well developed and armed with teeth or cutting plates . . . . ANCYLOSTOMATIDÆ (pp. 356–368).

48 (45). Bursa of males broad, well developed; buccal capsule lacking or rudimentary. . . . . . TRICHOSTRONGYLIDÆ (pp. 385–394).

49 (44). Males without a true bursa 50

50 (51). Worms pin-shaped, with buccal capsule . . . . OXYURIDÆ (pp. 400–406).

51 (50). Worms fleshy or elongate-cylindrical; without a buccal capsule 52

52 (53). Mouth typically with 2 lateral lips and accessory dorsal and ventral lips; caudal alæ of male well developed, supported by pedunculated papillæ; in tissues of anterior part of digestive tract . . . . . . *Gongylonema pulchrum* (p. 421).

53 (52). Mouth with 2 large trilobed lips 54

54 (55). Entire cuticula or anterior part of cuticula provided with minute ramified spines. GNATHOSTOMATIDÆ (pp. 425–429).

55 (54). Mouth internally armed with teeth; cuticula reflected forward over lips to form a collarette. . . . . *Physaloptera caucasica* (p. 429).

56 (1). Adult worms not primarily located in the digestive tract. 57

57 (68). In the outpocketings of the primitive digestive tract. 58

58 (63). Residing in the biliary or pancreatic ducts. . . . . (TREMATODES). 59

59 (60). With testes in front of the ovary. . . . DICROCŒLIIDÆ (pp. 186–190).

60 (59). With postovarian testes. 61

61 (62). Large fleshy flukes with dendritically branched testes, ovary and intestinal ceca. . . . . *Fasciola* spp. (pp. 162–169).

62 (61). Delicate transparent flukes, with branched or lobed testes and ovary but unbranched intestinal ceca. OPISTHORCHIDÆ (pp. 201–211).

63 (58). Residing in the respiratory passages. 64

64 (65). Fleshy distomate flukes encysted near the bronchioles. . . . . *Paragonimus westermani* (p. 215). (See also 74, this key.)

65 (64). Myosyringate nematodes. 66

66 (67). Bursa copulatrix of male well developed, short; buccal capsule well developed, without a thickened chitinous rim. . . . . *Syngamus kingi* (p. 355).

67 (66). Bursa copulatrix of male with stunted rays; buccal capsule practically lacking. . . . . *Metastrongylus apri* (p. 394).

68 (57). Adult worms located in foci having no direct connection with the digestive tract. 69

69 (70, 71). Adult worms enormous in size, in the kidneys or abdominal cavity of mammals; males with campanulate bursa . . . . *Dioctophyme renale* (p. 434).

70 (69, 71). Adult worms in the conjunctival sac. . . . . *Thelazia callipæda* (p. 431).

71 (69, 70). Adult worms in the portal blood system, liver tissues, lymphatics or connective tissues. . . . 72

72 (73). Diecious trematodes, living in the portal blood system. SCHISTOSOMATIDÆ (Chapters XI, XII).

73 (72). Helminths living in the musculature, liver tissues, lymphatics or connective tissues. 74

74 (75, 76). Trematodes encysted in the viscera, musculature or connective tissues .... *Paragonimus westermani* (p. 215). (See also 64, this key.)

75 (74, 76). Trichosyringate nematodes living in the liver tissues .... *Hepaticola heptica* (p. 332).

76 (74, 75). Myosyringate nematodes living in the lymphatics or connective tissues 77

77 (78). Filariform worms located in the lymphatics; larvæ (microfilariæ) "ensheathed" .... *Wuchereria bancrofti* (p. 439).

78 (77). Filariform worms migrating in the subcutaneous tissues 79

79 (80). Females enormously longer than males; anus and vulva atrophied in gravid females, which discharge their embryos through a rupture of the body wall near the mouth .... *Fuellebornius medinensis* (p. 472).

80 (79). Anus and vulva not atrophied in gravid females; larvæ discharged through vulva 81

81 (82). Microfilarial larvæ provided with a "sheath" when discharged by mother worms .... *Loa loa* (p. 460).

82 (81). Microfilarial larvæ lacking a "sheath" when discharged by mother worms 83

83 (84). Nuclear column in microfilariæ extending to caudal extremity .... *Acanthocheilonema perstans* (p. 466).

84 (83). Nuclear column in microfilariæ not extending to caudal extremity ..... *Onchocerca* spp. (pp. 454–459).

B. Larvæ in Advanced Stages of Development.

1 (8). Worms dorso-ventrally flattened 2

2 (5). Elongate, tape-like, body undifferentiated; in subcutaneous tissues, muscles, brain, etc. .... (PSEUDOPHYLLIDEAN CESTODES). 3

3 (4). With lateral branching or budding .... *Sparganum proliferum* (p. 259).

4 (3). Unbranched .... *Sparganum mansoni* and probably other related species (pp. 252–255).

5 (2). Oval in contour, with circumoral and ventral suckers. (Distomate flukes). 6

6 (7). Immature *Fasciola hepatica* aberrantly wandering in the tissues (p. 162).

7 (6). Immature *Paragonimus westermani* in abnormal foci (p. 215).

8 (1). With radial symmetry around a main antero-posterior axis 9

9 (18). Lacking intestinal tract, anterior end (scolex) usually provided with a circlet of hooks . . . . (CYCLOPHYLLIDEAN CESTODES). 10

10 (11). Minute solid procercoids imbedded in intestinal villi. *Hymenolepis nana* (p. 270).

11 (10). Larva consisting of a head or heads and an enveloping bladder; in liver, lungs, brain, muscles, etc. 12

12 (15). Each bladder containing only one head 13

13 (14). Scolex provided with a circlet of hooks . . . . *Cysticercus cellulosæ* of *Tænia solium* (p. 279).

14 (13). Scolex without hooks . . . . *Cysticercus bovis* of *Tænia saginata* (p. 287).

15 (12). Bladder containing several to many heads 16

16 (17). Heads derived from the primary bladder wall. *Multiceps* spp. (p. 289–292).

17 (16). Heads proliferated from secondary or tertiary cystic tissues arising from germinal layer of original bladder wall . . . . *Echinococcus granulosus* (*hydatids*) (pp. 292–300).

18 (9). Possessing intestinal tract . . . . (NEMATODES). 19

19 (20). Trichosyringate nematodes migrating through tissues or encysted in barrel-shaped or ellipsoidal capsules in muscular tissues . . . . *Trichinella spiralis* (p. 323).

20 (19). Myosyringate nematodes migrating through the tissues 21

21 (28). In subcutaneous tissues 22

22 (23). Having a bulbous head and cuticular spines . . . . . . *Gnathostoma* spp. (pp. 425–429).

23 (22). Lacking a bulbous cephalic swelling; cuticula aspinose 24

24 (25). Esophagus with a distinct cardiac bulbus . . . . *Rhabditid larvæ* (pp. 341–346).

25 (24). Esophagus lacking distinct cardiac bulbus 26

26 (27). Pharyngeal spears present . . . . *Ancylostomatid larvæ*. (See especially p. 363; also 384, describing "creeping eruption" caused by the migrating larvæ of *Ancylostoma braziliense* under the skin.)

27 (26). Immature filariid larvæ . (*Agamofilaria*) (pp. 470–472).

28 (21). Larvæ *en route* through the lungs 29

29. (30). Mouth surrounded by three lips . . . . . *Ascaris larvæ* (pp. 410).

30 (29). Mouth without definite lips . . . . Larvæ of hookworms, STRONGYLIDÆ, TRICHOSTRONGYLIDÆ and *Strongyloides* (pp. 351–355, 385–394, 336–340).

3. IDENTIFICATION OF EGGS AND LARVÆ DEVELOPING IN EGG MEMBRANES, DERIVED FROM ADULT WORMS IN HUMAN INFECTIONS.

The majority of helminth eggs are evacuated in the patient's feces. A few are recovered from urine and sputum. "Ensheathed" larvæ (*e. g.*, larvæ enveloped in an elongated egg membrane provided by the parent worm) are found in blood, lymph and serous exudates. Eggs of a few species are hatched in the uterus of the parent worm. Those of another small group are hatched at the time of egg-laying. The largest number, however, is oviposited in the unhatched condition. Some of these contain fully embryonated larvæ which are capable of hatching as soon as the egg comes into a favorable environment. Others require a period of several days to several weeks before the enclosed embryos become mature and are ready to escape from the egg capsule. The following key with the accompanying figure (Fig. 263) will aid in diagnosis of the more common eggs and encapsulated first stage larvæ recovered from man:

Diagnostic Key for the Identification of Helminth Ova and Larvæ Derived from Adult Worms in Human Infections.

1 (89, 104, 105). Eggs or first-stage larvæ recovered from the urine, sputum or feces 2

2 (7, 12). Recovered from the urine 3

3 (8). Eggs in the urine 4

4 (5). Large, elliptical, measuring 120 to 190 μ by 50 to 73 μ with terminal spine and fully embryonated larva. *Schistosoma hæmatobium* (Fig. 263 *G*).

5 (4). Medium-sized, oval, measuring 64 to 68 μ by 40 to 44 μ, with pitted surface except at the poles which are smooth; enclosed embryo immature . . . . *Dioctophyme renale* (Fig. 232 *D*).

Legend For Fig. 263

Fig. 263.—Eggs of the important human helminths. *A*, *Fasciola hepatica* or *Fasciolopsis buski; B*, *Metagonimus yokogawai; C*, *Dicrocœlium dendriticum; D*, *Clonorchis sinensis; E*, *Opisthorchis felineus; F*, *Paragonimus westermani; G*, *Schistosoma hæmatobium; H*, *Schistosoma bovis; I*, *Schistosoma mansoni; J*, *Schistosoma japonicum; K*, *Diphyllobothrium mansoni; L*, *Diphyllobothrium latum; M*, *Dipylidium caninum; N*, *Hymenolepis nana; O*, *Hymenolepis diminuta; P*, *Tœnia* spp.; *Q*, *Tœnia saginata* in mother embryonic membrane; *R*, *Trichostrongylus orientalis; S. Gnathostoma spinigerum; T_{1-3}*, *Ascaris lumbricoides; U*, *Enterobius vermicularis; V_{1-2}*, *Ancylostomá duodenale; W*, *Heterodera radicicola; X*, *Macracanthorhynchus hirudinaceus; Y*, *Trichocephalus trichiurus*. All × 250, except *B*, *D*, and *E*, which are × 500. (Partly original, partly adapted from various authors.)

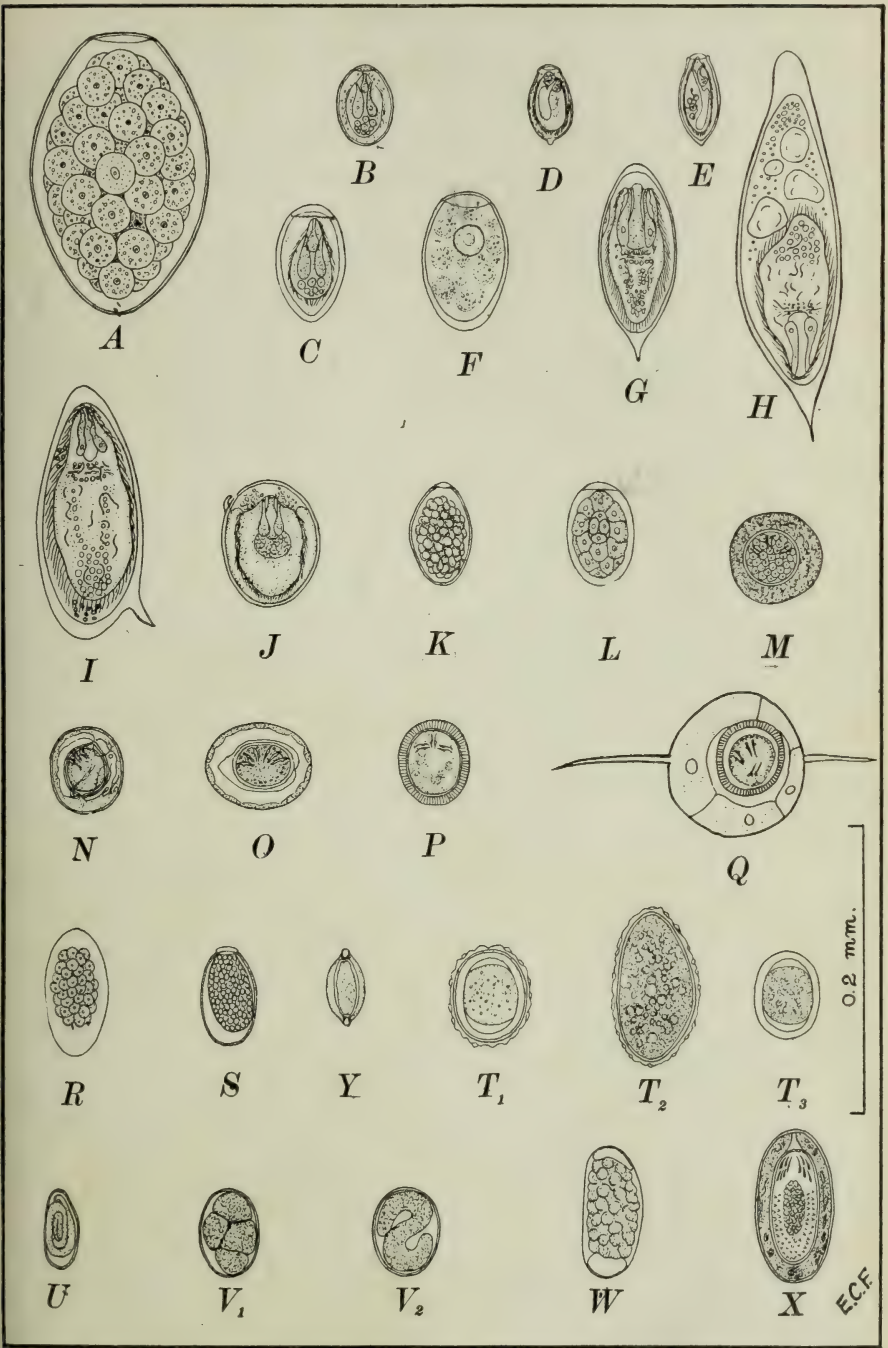

FIG. 263 *Faust's Human Helminthology.*

6 (3). Larvæ in the urine; rhabdiasid species (pp. 341–342) accidentally introduced into the urino-genital tract, or *Microfilaria bancrofti* (Fig. 235) in chylous urine (pp. 439–444).

7 (2, 12). Recovered from the sputum, or from the feces containing eggs derived from swallowed sputum. (Eggs only[1]) 8

8 (9). Broadly oval, operculate, with thick shell, measuring 87 to 125 μ by 52 to 66 μ dark golden-brown in color, containing undeveloped embryo . . . . *Paragonimus westermani* (Fig. 263 *F*).

9 (8). Non-operculate 10

10 (11). Ellipsoidal, measuring 50 to 100 μ by 39 to 72 μ, hyaline, containing fully embryonated larva . . . . . . *Metastrongylus apri.*

11 (10). Oval, hyaline, with polar thickenings, containing larva in early stages of segmentation . . . . *Syngamus kingi* (Fig. 195 *A*).

12 (2, 7). Recovered from the feces 13

13 (86). *Eggs* in the feces or muco-fecal exudate 14

14 (31). Operculum present 15

15 (23). Medium- to large-sized eggs, with immature larvæ . . 16

16 (19, 20). Large, hyaline or light golden-yellow, with small opercular cap closely fitted on the shell 17

17 (18). Opercular cap nearly flat; egg measuring 130 to 145 μ by 70 to 90 μ . . . . . *Fasciola hepatica* or *Fasciolopsis buski* (Fig. 263 *A*);
measuring 150 to 190 μ by 75 to 90 μ . . . . . *Fasciola gigantica;*
measuring 150 μ by 72 μ . . . . *Gastrodiscoides hominis;*
measuring 122 to 130 μ by 75 to 80 μ . . . . . *Watsonius watsoni.*

18 (17). Opercular cap narrowly rounded; eggs somewhat more elliptical;
measuring 88 to 111 μ by 53 to 74 μ . . . . *Echinostoma ilocanum* (pp. 178–179);
measuring 120 to 130 μ by 80 to 90 μ . . . . *Echinostoma malayanum* (pp. 179–180);
measuring 132 to 154 μ by 79 to 85 μ . . . . *Echinostoma jassyense* (pp. 180–181);

[1] Larvæ of the hookworms, *Trichostrongylus*, *Strongyloides* or *Ascaris* which may possibly be recovered from the sputum represent the filariform stage of development. Furthermore, they have been derived from parent worms parasitic in other host individuals.

measuring 90 to 125 μ by 60 to 75 μ. . . . .
Echinostoma sufrartyfex (Fig. 86 *B*);
measuring 90 to 135 μ by 55 to 95 μ. . . . .
Echinochasmus perfoliatus (Fig. 87 *B*);

19 (16, 20). Moderately large eggs; broadly oval, with flat broad operculum and thick dark-brown shell, 80 to 125 μ by 52 to 66 μ. . . . .
Paragonimus westermani (Fig. 263 *F*).

20 (16, 19). Medium-sized eggs, with small, poorly-defined operculum; shell thin, light-straw color . . . . . .
(PSEUDOPHYLLIDEAN CESTODES[1]). 21

21 (22). Eggs broadly oval; measuring 55 to 80 μ by 41 to 56 μ
Diphyllobothrium latum (Fig. 130; Fig. 263 *L*);
measuring 75 μ by 50 μ. . . . . . . *D. cordatum* (p. 249);
measuring 59 μ by 41 μ. . . . *D. parvum* (pp. 249–250);
measuring 63 to 68 μ by 50 μ. . . . .
Diplogonoporus grandis (Fig. 143).

22 (21). Eggs more narrowly ellipsoidal, measuring 52 to 68 μ by 32 to 44 μ. . . . . *Diphyllobothrium mansoni* or *D. houghtoni* (Fig. 263 *K*).

23 (15). Small, thick-shelled eggs, with fully embryonated larvæ 24

24 (27). Eggs containing larvæ with bilaterally symmetrical arrangement of internal organs 25

25 (26). Eggs small, oval, golden-brown in color, with narrowly rounded operculum and usually an abopercular thickening;
measuring 28 to 30 μ by 15 to 17 μ. . . . .
Heterophyes heterophyes (Fig. 91);
measuring 25.3 to 25.9 μ by 14.3 to 15 μ. . . . .
Heterophyes katsuradai;
measuring 26.5 to 28 μ by 15.5 to 17 μ. . . . .
Metagonimus yokogawai (Fig. 94; Fig. 263 *B*).

26 (25). Eggs somewhat larger (38 to 45 μ by 22 to 30 μ), elliptical, with one side usually somewhat slightly flattened; having a broad dome-shaped operculum; color dark brown . . . . . *Dicrocœlium dendriticum* or *Eurytrema pancreaticum* (Fig. 263 *C*).

27. (24). Eggs containing embryos with asymmetrical arrangement of internal organs 28

28 (29, 30). Measuring 27.3 to 35.1 μ by 11.7 to 19.5 μ. . . . . .
Clonorchis sinensis (Fig. 103; Fig. 263 *D*).

29 (28, 30). Measuring 30 μ by 11 μ. . . . .
Opisthorchis felineus (Fig. 99; Fig. 263 *E*).

[1] After an incubation period of one to five weeks in water these eggs contain ciliated embryos with 3 pairs of hooks. (See Figs. 131, 140.)

30 (28, 29). Measuring 26 μ by 13 μ. . .*Opisthorchis viverrini.*
31 (14). Operculum lacking. 32
32 (39). Shells with a terminal or lateral spinose process; eggs containing fully embryonated larvæ with ciliated epithelium. 33
33 (38). Eggs elongate-oval. 34
34 (37). Provided with terminal spinose prolongation of shell. 35
35 (36). Egg very large, measuring 170 μ by 45 μ. . . . . *Schistosoma bovis* (Fig. 263 *H*).
36 (35). Egg moderately large, measuring 120 to 160 μ by 40 60 μ. . . . .*Schistosoma hæmatobium.* (Rare in feces, common in urine. See 4, this key.)
37 (34). Provided with distinctly projecting lateral spine; measuring 140 to 165 μ by 60 to 70 μ. . . . . *Schistosoma mansoni* (Fig. 263 *I*).
38 (33). Eggs broadly oval, with abbreviated lateral incurved thorn-like spine, sometimes difficult to locate; measuring 70 to 100 μ by 50 to 65 μ. . . . . *Schistosoma japonicum* (Fig. 263 *J*).
39 (32). Shell lacking a spinose process. 40
40 (55). Shell spheroidal, spherical-ovate, ovate or oval-elongate; hyaline; containing a fully-developed embryo with 3 pairs of hooks. . . . . (CYCLOPHYLLIDEAN CESTODES). 41
41 (44). Inner shell thick, with radial striations. . . . . (*Tænia* spp[1].) 42
42 (43). Embryonic egg-membrane provided with a pair of lateral attentuated processes; inner shell measuring 35 to 40 μ by 20 to 30 μ. . . . . *Tænia saginata* (Fig. 163 *A*, *B*; Fig. 263 *P*)
43 (42). Embryonic egg-membrane lacking lateral attenuated processes; inner shell measuring about 36 μ by 31 μ *Tænia solium* (Fig. 156);
inner shell measuring 42 μ by 33 μ. . . . . *Tænia confusa;*
inner shell measuring 34 to 39 μ by 31 to 33 μ. . . . . . *Tænia africana.*
44 (41). Inner shell membranous. 45
45 (50). Eggs enclosed in groups in embryonic membrane. . . . 46
46 (47). Eggs spherical (25 to 30 μ), reddish tinged, with delicate hooklets; 8 to 15 in each mother capsule which is broadly oval. . . . . *Dipylidium caninum* (Fig. 149 *C, D;* Fig. 263 *M*).

[1] Difficult to differentiate from one another, since the embryonic egg-membrane has usually been shed before eggs are set free in the feces. Greater reliance can be placed in characteristic differences of the gravid proglottids (Fig. 126, *1–4*).

47 (46). Eggs elongate-oval or elliptical 48
48 (49). Several in each mother capsule; each measuring 50 to 64 μ by 14 to 23 μ . . . . . *Davainea madagascariensis* (Fig. 150 *C*).
49 (48). At most three in each mother capsule; each measuring 99 μ by 46 μ . . . . *Davainea formosana.*
50 (45). Only one egg in each embryonic membrane 51
51 (52). Inner shell drawn out on one side into a bicornuate process . . . . *Bertiella satyri* (Fig. 148 *C*).
52 (51). Inner shell rounded or oval 53
53 (54). Eggs spherical or subspherical, measuring 30 to 47 μ over all; middle membrane provided with two polar thickenings, from each of which there arise 4 to 8 filamentous processes . . . . *Hymenolepis nana* (Fig. 151 *C;* Fig. 263 *N*).
54 (54). Eggs oval, measuring 60 μ by 86 μ over all; inner membrane provided with polar thickenings but lacking filamentous processes . . . . *Hymenolepis diminuta* (Fig. 153 *C;* Fig. 263 *O*).
55 (40). Shell oval, considerably longer than broad, usually with a very regular characteristic contour; or broadly oval to subspherical with superficial mammillations. . . . . (NEMATHELMINTHES). 56
56 (67). Containing fully-developed embryo 57
57 (60, 64). Shell very symmetrical; embryo provided with a circlet of hooklets near anterior end 58
58 (59). Measuring 80 to 100 μ by 42 to 55 μ . . . . *Macracanthorhynchus hirudinaceus* (Fig. 256; Fig. 263 *X*).
59 (58). Measuring 85 to 118 μ by 40 to 52 μ . . . . *Moniliformis moniliformis* (Fig. 259).
60 (57, 64). Shell usually more or less flattened on one side . . 61
61 (62, 63). Measuring 50 to 60 μ by 20 to 30 μ . . . . *Enterobius vermicularis* (Fig. 219 *C;* Fig. 263 *U*).
62 (61, 63). Measuring 125 μ by 40 μ . . . . *Syphacia obvelata* (Fig. 221 *E*).
63 (61, 62). Measuring 82 to 120 μ by 24 to 43 μ; at times concavoconvex or reniform . . . . . . *Heterodera radicicola* (Fig. 190, *4;* Fig. 263 *W*; see also 79, this key).
64 (57, 60). Shell thick, broadly ovate 65
65 (66). Measuring 50 to 70 μ by 25 to 37 μ . . . . *Gongylonema pulchrum* (Fig. 228 *D*).
66 (65). Measuring 44 to 65 μ by 32 to 45 μ . . . . *Physaloptera caucasica* (Fig. 230 *E*).
67 (56). Containing unsegmented embryos or those in early stages of development 68

68 (72). Shell with polar differentiation 69
69 (70, 71). Shell barrel-shaped, with a plug at each pole; egg measuring 50 to 54 μ by 22 to 23 μ........ *Trichocephalus trichiurus* (Fig. 263 *Y*).
70 (69, 71). Shell pitted, with a single polar cap; egg measuring 65 to 70 μ by 38 to 40 μ; embryo in morula, gastrula or postgastrula stage of development. *Gnathostoma spinigerum* (Fig. 229 *G*; Fig. 263 *S*), or *Gnathostoma hispidum.*
71 (69, 70). Shell with two polar caps ..... *Syngamus kingi* (Fig. 195 *A*).
72 (68). Shell without polar differentiation 73
73 (79). With superficial mammillated albuminous layer..... 74
74 (75). Broadly oval, measuring 40 to 65 μ by 35 to 50 μ, with prominent mammillations of superficial layer, which is usually bile-stained; or more elongate-oval, measuring about 35 μ by 75 μ, with very irregular mammillations, or lacking albuminous layer ...... *Ascaris lumbricoides* (Fig. 222 *D*; Fig. 263 T_{1-3}).
75 (74). Shell subspherical 76
76 (77, 78). Measuring 75 μ by 85 μ .... *Toxocara canis* (Fig. 225 *E*).
77 (76, 78). Measuring 65 μ by 75 μ in diameter .... *Belascaris cati* (Fig. 226 *E*).
78 (76, 77). Measuring 65 μ in diameter .... *Lagochilascaris minor* (Fig. 227 *C*)
79 (73). Shell lacking an outer albuminous layer or superficial mammillations 80
80 (85). Shell thin, oval 81
81 (84). With obtusely rounded ends 82
82 (83). Flattened or concave on one side, convex on the other, measuring 82 to 100 μ by 24 to 43 μ .... *Heterodera radicicola* (Fig. 190; Fig. 263 *W*; see also 63, this key).
83 (82). Symmetrically shaped; both sides slightly convex, embryos usually in early stages of segmentation. ANCYLOSTOMATIDÆ and STRONGYLIDÆ (Fig. 263 V_{1-2}).[1]
Measuring 56 to 61 μ by 34 to 38 μ .... *Ancylostoma duodenale;*
measuring 65 μ by 32 μ .... *Ancylostoma braziliense;*

[1] Eggs of *Strongyloides stercoralis*, measuring 50 to 58 μ by 30 to 34, μ and containing fully-developed rhabditiform larvæ, may at times be recovered from diarrheic stools or after a severe purge. (See 87, this key.)

measuring 63.8 μ by 40.4 μ. . . . .
Ancylostoma caninum;
measuring 64 to 76 μ by 36 to 40 μ. . . . .
Necator americanus;
measuring 60 μ by 40 μ. . . . . . *Ternidens deminutus;*
measuring 60 to 63 μ by 27 to 40 μ. . . . .
Œsophagostomum apiostomum.
(The eggs of *Ancylostoma* spp., *Necator, Ternidens* and *Œsophagostomum* can be differentiated from one another only with the greatest difficulty. If they are cultured to the filariform stage generic differentiation can be made. At the present state of our knowledge specific diagnosis can be made only by the experimental infection of the appropriate host and recovery of the adult worms after administration of specific anthelminthics.)

84 (81). With more or less pointed ends and broadly rounded sides; embryos usually in morula stage of development. . . . . TRICHOSTRONGYLIDÆ (Fig. 263 *R*).
Measuring 73 to 80 μ by 40 to 43 μ. . . . .
Trichostrongylus colubriformis;
measuring 76 to 80 μ by 43 to 46 μ. . . . .
Trichostrongylus probolurus;
measuring 84 to 90 μ by 46 to 50 μ. . . . .
Trichostrongylus vitrinus;
measuring 75 to 90 μ by 39 to 47 μ. . . . .
Trichostrongylus orientalis;
measuring 75 to 95 μ by 40 to 50 μ. . . . .
Hæmonchus contortus;
measuring 95 to 110 μ by 50 to 55 μ. . . . .
Mecistocirrus digitatus.

85 (80). Shell broadly oval, thick, measuring about 38 μ by 60 μ. . . . . *Ascaris lumbricoides* (lacking albuminous coat).

86 (13). *Larvæ* in feces. 87

87 (88). Rhabditiform myosyringate larvæ, measuring 200 to 250 μ by 16 μ, with a distinct cardiac bulbus. . . .
Strongyloides stercoralis (Fig. 186; see also footnote to 83, this key).

88 (87). Trichosyringate larvæ, measuring 90 to 100 μ by 6 μ.
Trichinella spiralis (Fig. 180 *C*).

89 (1, 105, 104). Eggs or first-stage larvæ recovered from peripheral blood, lymph or subcutaneous tissues. 90

90 (91). Trichosyringate larvæ, measuring 90 to 100 μ by 6 μ; recovered from peripheral blood. . . . .
Trichinella spiralis (Fig. 180 *C*).

91 (90). Filariform larvæ .... (Superfamily FILARIOIDEA) 92
92 (97). Larvæ "ensheathed" 93
93 (94). Larvæ without nuclei in terminal portion of tail; in peripheral blood or localized lymph accumulations. *Microfilaria bancrofti* (Fig. 235).
94 (93). Larvæ with nuclei in terminal portion of tail 95
95 (96). Continuous column of nuclei extending to caudal termination .... *Microfilaria loa* (Fig. 246).
96 (95). Only two distinctly separated nuclei in caudal extremity .... *Microfilaria malayi* (Fig. 249).
97 (92). Larvæ lacking sheath 98
98 (99). With long, attentuated postanal portion; digestive tract well differentiated; movement stiff, wiry; found only in terminal portion of tunnel of adult worm or around opening of tunnel ... *Microfilaria* of *Fuellebornius medinensis* (Fig. 250 *D*).
99 (98). Lacking long-attenuated postanal portion; digestive tract undifferentiated; movement more or less free and rapid; in blood or subcutaneous tissues 100
100 (103). Larvæ without nuclei in terminal portion of tail 101
101 (102). Most distal nuclei of tail oval in shape; occasionally in peripheral blood, more commonly in localized nodules or subcutaneous tissues ... *Microfilaria* of *Onchocerca volvulus* and *O. cæcutiens* (Fig. 242 *E*).
102 (101). Most distal nuclei elongate in shape; in peripheral blood .... *Microfilaria ozzardi* (Fig. 248 *B*).
103 (100). Terminal portion of tail provided with column of nuclei; in peripheral blood .... *Microfilaria perstans* (Fig. 247 *D*).
104 (1, 89, 105). "Ensheathed" larvæ coiled in egg-membrane having a ballooned float; in lacrimal or conjunctival exudate ...... *Thelazia callipæda.*
105 (1, 89, 104). Eggs with barrel-shaped contour and mucoid polar plugs; imbedded in liver substance ... *Hepaticola hepatica* (Fig. 183 *B*).

4. FECES CONTAMINATORS, ARTEFACTS AND PROTOZOAN CYSTS LIABLE TO BE CONFUSED WITH PARASITIC HELMINTHS AND THEIR OVA.

The diagnostician is frequently puzzled by finding in human exudates objects which more or less strikingly resemble ova of parasitic helminths. The majority of these are contaminators or artefacts. A considerable share is of plant origin; others are animal cells; still others are artefacts pure and simple. Mucus casts formed in the respiratory, urinary and intestinal tracts may more or less

resemble adult helminths, but inspection even with a good hand lens will prove that they are not genuine organisms. The long fibers

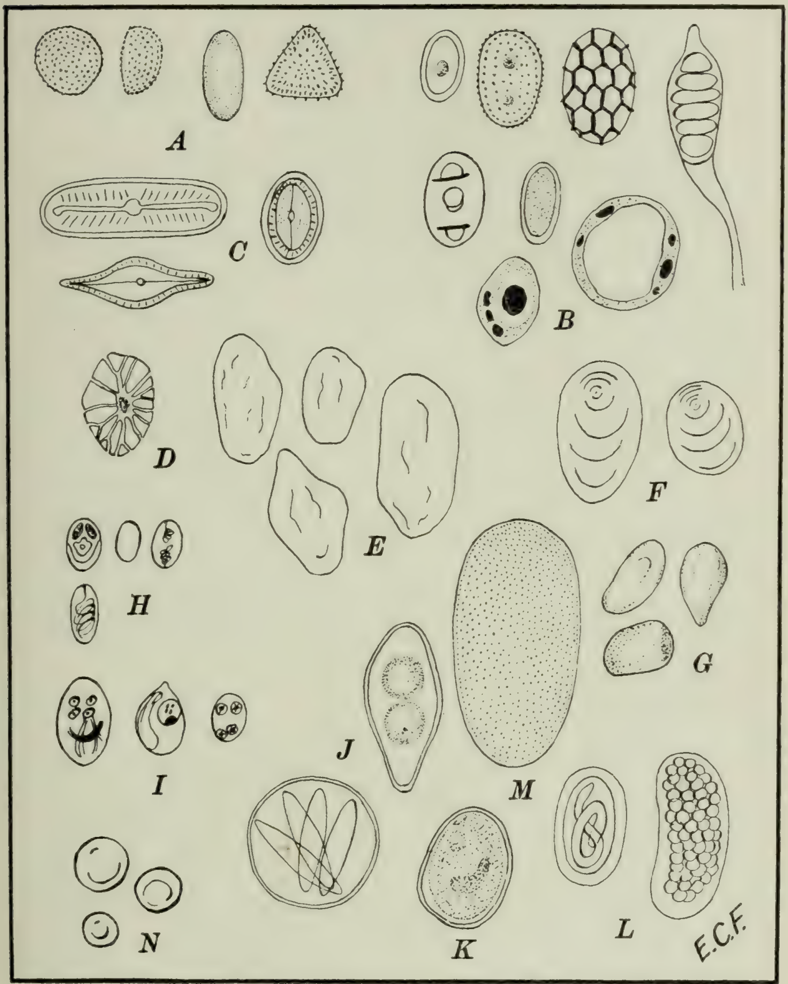

FIG. 264.—Fecal contaminators, artefacts and protozoan cysts in human feces liable to be confused with parasitic helminth eggs. *A*, pollen grains; *B*, fungus and yeast spores; *C*, diatoms; *D*, stone cell of fruits such as the pear; *E*, parenchymatous cells of vegetables such as the Cucurbitaceæ; *F*, starch grains; *G*, partly digested protein particles; *H*, myxosporidian and microsporidian cysts ingested in parasitized animal tissue; *I*, cysts of intestinal protozoa; *J*, coccidia cysts; *K*, *Balantidium* cyst; *L*, eggs of nematodes accidentally ingested; *M*, egg of mite; *N*, oil globules. × 500–800. (Partly original, partly compiled from various sources.)

of many semi-woody plants and such fruits as the banana, when digested out of their tissue-matrix may also be at first mistaken for

nematodes, but examination with low power of the microscope will serve to dispel this first impression.

Plant cells which are passed through the intestinal tract in an excellent state of preservation are at times more difficult to eliminate diagnostically. Many of these are of such a size and shape as to come within the common definition of helminth eggs. But there is always some structure, either external or internal, which serves to differentiate them. The majority of such cells are referable to pollen grains (Fig. 264 *A*), fungus or yeast spores (Fig. 264 *B*), diatoms (Fig. 264 *C*), stone cells of such plants as pears (Fig. 264 *D*), or parenchymatous cells of succulent plants such as melons (Fig. 264 *E*). Pollen grains may be spherical, oval, tetrahedral or elongate, and may be covered with a smooth or sculptured epidermis. They are of a constant size for each species. Internally they are readily distinguished from helminth eggs. Fungus spores and yeast cells are usually smaller than helminth eggs; they may be oval or subspherical and in some cases may have a stipe-attachment at one end. They are constant in size but are usually easy to differentiate from helminth eggs. Diatoms are oval, elongate or naviculate, are constant in size, but have characteristic markings and are flat in one plane. Stone cells from such fruits as pears are usually oval-polygonal in shape and are provided with radiating canals converging at the center of the cell. They are not constant in size. Parenchymatous cells are irregularly oval, polygonal or elongate, inconstant in size, and slightly wrinkled superficially. Internally they are usually devoid of structure, although a nucleus may at times be found. Furthermore, starch grains, intact or partially digested (Fig. 264 *F*), may at times be confused with helminth eggs but may be readily differentiated since they are solid structures consisting of laminæ laid down around an acentric core. Likewise particles of protein (Fig. 264 *G*) the contours of which have been rounded out by partial digestion may confuse the beginner.

Cells of animal origin, liable to be confused with helminth ova, found in human excreta and not belonging to parasitic helminths lodged in the body, consist of cysts of protozoa and eggs of worms or acarinids accidentally taken into the body. The protozoan cysts consist of those originating from parasitized animal tissue taken into the digestive tract and those which are the products of human protozoan parasites. The only members of the former group (Fig. 264 *H* and *J*, lower left) thus far observed are microsporidian, myxosporidian and coccidian cysts, ingested in parasitized fish flesh. The cysts of the microsporidia and myxosporidia are oval in shape, much smaller than helminth ova, and have definite internal structures which serve to differentiate them. The coccidian cysts of the genus *Eimeria* are spherical (20 to 45 μ in diameter) and contain four characteristic internal spore-forming bodies. The cyst of

the coccidian parasite in the human intestine (*Isospora hominis* is irregularly oval with obtuse ends, measures 25 to 33 μ by 12.5 to 16 μ, and has one or two internal spore-forming bodies. The cysts of *Balantidium coli* which are derived from this human ciliate infection are subspherical, measure about 50 by 60 μ, and contain the encysted protozoan which has a reniform macronucleus and a distinct cytostome. In addition to the eggs of the plant nematode, *Heterodera radicicola,* which have been observed by several investigators in human feces the present author has found eggs resembling those of *Physaloptera,* with a thick hyaline shell and containing a fully embryonated nematode larva which were passed once in large numbers by a Chinese student but were absent on repeated subsequent examinations.

Again, eggs of mites (Fig. 264 *M*) which have been accidentally ingested, may be confused with eggs of helminths. Such eggs are broadly oval with quite broad ends, are usually considerably larger than helminth eggs, and either contain a homogenous semi-opaque embryo or the larval stage of the mite, with 6 pairs of legs.

Finally, air bubbles and spherical droplets of oil (Fig. 264 *N*) in fecal films require to be eliminated from consideration as objects which might be confused with helminth ova.

5. CONCENTRATION METHODS FOR THE QUALITATIVE AND QUANTITATIVE DETERMINATION OF HELMINTH EGGS AND LARVÆ.

A. Concentration of Eggs in Feces.—The concentration of helminth eggs by various methods has a two-fold purpose, (1) the detection of eggs in light infections where ordinary fecal smears are negative, and (2) the saving of time in diagnosis due to the yield of a larger number of eggs per microscopic field. In addition, the more refined techniques have come to serve an additional function, namely, the more or less accurate determination of the number of eggs per unit of feces as an estimate of the number of worms harbored in a given infection. The following concentration methods are useful in increasing the number of eggs per unit microscopic field: (1) clarification of thick dried films; (2) straining out coarse roughage and undigested food; (3) centrifugation; (4) floatation, and (5) centrifugal floatation. These techniques will be taken up *ad seriatim* and their several merits and short-comings discussed.

1. **Clarification of Thick Dry Films.**—Several workers have found that thick dry fecal smears may be cleared by using cedar oil, wintergreen oil or paraffin oil. Such technique will allow concentration up to ten-fold the ordinary fecal smear. For *Ascaris, Trichocephalus, Tænia* and *Hymenolepis* ova the method gives excellent

results. *Clonorchis, Opisthorchis* and *Metagonimus* eggs can be found without difficulty but the internal characters essential for differentiating the eggs of the **Opisthorchidæ** from those of the **Heterophyidæ** are not distinguishable. Eggs with thin shells, such as *Ancylostoma, Trichostrongylus* and *Diphyllobothrium,* are not visible because of their complete transparency, while those of *Fasciola, Fasciolopsis* and *Schistosoma japonicum* are so shrunken as to be unrecognizable.

2. **Straining Out Coarse Roughage and Undigested Food.**—This is effected by using a bolting cloth or brass wire screen of 100 to 120 meshes per linear inch. It eliminates the bulky particles and in so doing concentrates the egg-containing fecal elements. The process is relatively slow and requires considerable care in cleaning in order to wash out eggs that might become lodged in the meshes. A metal basket with such a wire sieve is very desirable for use in searching for small worms passed in the feces or in examining the intestinal contents at autopsy.

3. **Centrifugation.**—For this method feces should be diluted ten to twenty times with water and the thoroughly comminuted specimen placed in centrifuge tubes and spun for one to two minutes at a speed of 1000 revolutions per minute. This throws down the ova and larvæ, which are all heavier than the ordinary fecal elements and allows the examiner to draw off and examine a small amount of the bottommost sediment. This is the most satisfactory concentration technique for operculate eggs, including *Diphyllobothrium, Fasciola* and *Fasciolopsis, Clonorchis, Opisthorchis, Metagonimus* and *Heterophyes,* as well as for *Schistosoma* eggs in the feces.

4. **Flotation.**—The value of this technique depends on the fact that a saturated brine solution has a greater specific gravity than most helminth eggs, so that eggs in feces which have been mixed with brine float to the surface film, while the fecal material gradually sinks to the bottom. The several methods based on this principle are superior to that of centrifugation for all eggs except operculate ones and those of schistosomes. The larger operculate eggs, such as *Fasciolopsis, Echinochasmus* and *Diphyllobothrium* "pop" open in brine solution and sink to the bottom. The smaller, thick-shelled eggs, such as those of *Clonorchis, Metagonimus* and *Dicrocœlium,* are denser than the saline medium (in fact, denser than pure glycerin) and sink rather than levitate. *Schistosoma* eggs shrink into an unrecognizable condition in a brine solution.

The brine solution may be made up to saturation by using crude salt, which usually has a slightly greater density than refined salt. The solution should be filtered and kept in a stoppered bottle. The specific gravity will vary between 1120 and 1210, depending in part on the temperature and in part on the crude elements in the brine.

Kofoid-Barber Brine Flotation-loop Technique.—This consists essentially of the comminuting of the fecal specimens, in the paraffined cups in which they have been collected, with two to three times their volume of brine, forcing the coarse roughage to the bottom with a disk of steel wool, allowing the mixture to stand for one hour, then looping off the surface film and examining it on a fecal slide under a microscope. The manipulation of looping is the serious drawback to the technique, since the number of ova in the surface film removed varies according to the type of stool and to the part of the film looped off, and since one skimming usually removes only a part of the ova in the mixture.

Willis-Molloy Technique.—This consists in the dilution of 0.5 to 1 cc. of the fecal specimen with 10 to 20 parts of brine in a cylinder-container of about 2.5 cm. diameter, the liquid being sufficient so that the mixture comes exactly to the surface of the container and forms a definite meniscus. A grease-free fecal slide (50 x 75 mm.) is carefully superimposed upon the meniscus and allowed to remain for one hour, after which it is carefully removed, inverted and direct examination made of the film attached to the slide. In the author's experience the optimum times is much shorter, ranging from ten to fifteen minutes. If the procedure is properly carried out a large proportion of all the eggs in the specimen should have levitated to the surface film and have been removed. This method is one giving maximum results for the least effort in field operation where non-operculate eggs exclusive of *Schistosoma* are to be diagnosed. It effects a greater concentration of eggs than the Kofoid-Barber technique. However, it cannot be used as an accurate egg-count technique.

Direct Centrifugal Flotation.—This technique has been developed by Lane in an attempt to overcome some of the difficulties inherent in the simpler methods. Without question it is the most precise and delicate method thus far devised and removes all but a negligible amount of the eggs of *Ascaris,* hookworm, *Trichocephalus* and *Trichostrongylus* from a specimen. But what it has developed in accuracy has been offset by its comparative complexity.

One cubic centimeter of feces is measured out from the specimen and placed in a special ground-top centrifuge tube, which is then filled with tap water to within 25 mm. of the top. The tube is then corked, and thoroughly shaken until the feces is thoroughly commingled with the water. It is then placed in the centrifuge carriage and spun for one minute at 1000 revolutions per minute. The supernatant fluid is then poured off and the tube is nearly filled with a saturated brine solution, corked and agitated until the suspension is even. The tube is then returned to the carriage, filled brim-full with additional brine solution, and covered with a thick cover-glass which is anchored to the four horns of the special carriage

bucket. It is then centrifuged for one minute at 1000 revolutions per minute and the cover-glass removed, placed on a plasticine support on a slide and examined as a hanging drop. With a brine solution of 1200 specific gravity a rapid-lift direct centrifugal flotation will deliver 70 to 95 per cent of all of the eggs in the sample on the first spin, while second and third spins will deliver an appreciable balance and a fourth spin a relatively negligible number if any. This technique is therefore sufficiently accurate for estimating the number of *Ascaris,* hookworm or *Trichocephalus* worms present in any given infection, using the number of eggs per female worm per gram of feces as the conversion figure (see pp. 530–531). The method is, however, too complicated for field work, although it is suitable for a central diagnostic laboratory where the maximum accuracy is desired and good technical assistance is available.

Stoll Egg-count Technique.—This technique was devised for the accurate counting of helminth eggs in an unconcentrated fecal specimen. Three grams of feces are weighed into a large thick-glass test-tube graduated up to 45 cc. Decinormal sodium hydroxide solution is then added up to the 45-cc. mark. Ten small glass beads are then added, the tube is closed with a rubber stopper and agitated until the mixture is homogeneous. If the sample is hard it is well to let it digest in the liquid over night. Immediately after shaking, 0.15 cc. of the suspension is drawn off with a graduated pipette, placed on a fecal slide (50 x 75 mm.) and covered with a 22 x 40 mm. cover-slip. The total number of eggs in the preparation is then counted. Multiplying the count by 100 gives the number of eggs per gram of feces. This method has been found by various investigators to be accurate to within 10 to 20 per cent. Multiplying the total count per gram of feces by the average daily output of feces per individual gives the total egg production *per diem.* Faust and Khaw (1926, 1927) have found that fecal specimens over a period of ten to fourteen days are desirable in order to obtain an accurate daily average, and that much greater dependence can be placed on average daily output of eggs than on eggs per gram of feces, since the consistency of the specimen varies too widely to permit of accurate estimate of its water content. The Stoll technique has been employed in conjunction with worm-counts in *Necator, Ancylostoma, Ascaris, Clonorchis* and *Fasciolopsis* infections in order to determine the egg-laying capacity of these species of worms per unit of time or per unit of formed fecal output. The following figures may be considered as relatively accurate estimates for these worms: *Necator,* ca. 9000 eggs per female *per diem* (Stoll, 1923); *Ancylostoma,* several times that of *Necator* (Sweet, 1924, Cort, Stoll and Grant, 1926); *Ascaris,* ca: 72,000 eggs per female *per diem* (Brown and Cort, 1927); *Clonorchis,* 2400 eggs per worm *per diem* in cats, 1600, in guinea-pigs (*e. g.,* egg-laying capacity variable with the host; Faust

and Khaw, 1926, 1927); *Fasciolopsis*, 25,000 eggs per worm *per diem* (Stoll, Cort and Kwei, 1927). Using these figures the average daily egg production in any given infection may be used to estimate the number of egg-producing individuals in the patient. For hermaphroditic species such as *Clonorchis* and *Fasciolopsis*, this product constitutes the estimated number of worms in the infection; for unisexual species, such as *Ascaris* and hookworms, it is the estimate for females only and the total number of worms may be reckoned as twice that number, since the numbers of males and females are usually about equal.

B. Concentration of Larvæ.—The methods employed for concentration of larvæ in blood and lymph, in feces, or in soil contaminated with feces containing eggs or larvæ, has the same ends in view as the concentration of eggs in feces, namely, the diagnosis of light infections and the saving of time.

Blood, Lymph and Chylous Urine.—*Thick Film Methods.*—These methods have already been described (pp. 499–500, Fig. 261). The thick film is dried, dehemaglobinized in water or dilute hydrochloric acid and examined (1) in the wet, unfixed condition, either unstained or stained with vital dyes, (2) or air dried, fixed in methyl alcohol and stained by Giemsa or hematoxylin methods.

Centrifugation.—Defibrinized and dehemaglobinized blood, or lymph or chylous urine, is concentrated by centrifuging for about one minute at 1000 revolutions per minute, the supernatant fluid decanted and the sediment examined for the larvæ. These may be vitally stained or the film air-dried, fixed and permanently stained.

Feces or Soil.—Larvæ in the feces, as for example *Trichinella* or *Strongyloides*, may occasionally be diagnosed from unconcentrated fecal films but centrifugation, in the same manner as has been described for larvæ in the blood, lymph or urine, is usually indicated wherever there is a suspicion of these infections being present. A more exact technique for *Strongyloides*, which has much to recommend it, consists (1) in the culture of the fecal sample in a covered Petri dish and the recovery of the larvæ from the water of condensation on the underside of the cover, or (2) in the use of the Baermann apparatus.

Culture Methods.—The more simple technique applies equally well to larvæ of *Strongyloides* or other rhabdiasate species, to hookworms, *Trichostrongylus* or other rapidly developing eggs in the feces, or to parasitic or free-living nematodes in the soil. The sample is thoroughly mixed with an equal amount of sterile sand or animal charcoal and placed on a circle of filter paper in a Petri dish (preferably of unglazed porcelain) or in a stender jar. The container is covered with a glass lid, so that water of condensation collects on the under side of the lid. In the course of several hours to a few days, depending on the species and the state of development at the

time of culturing, the majority of the larvæ will be found to have collected in the water of condensation, and may be removed to a microscopic slide and examined. By this culture method practically the entire number of larvæ in the sample can be drawn off with the Baermann apparatus. (See below.)

Eggs of *Ascaris*, *Trichocephalus* and other nematode species which require several weeks for development to the fully embryonated stage may be placed on moistened circles of filter paper in covered Petri dishes. Development may be accelerated by keeping the culture in contact with a 2 per cent solution of formaldehyde. This solution must be thoroughly washed off before the embryonated larvæ are used for experimental feedings.

Eggs of *Schistosoma* species are fully embryonated on being passed in feces or urine and require only a dilution of the medium to secure hatching. This can be effected in the case of a fecal specimen by washing the specimen, decanting the supernatant fluid, allowing the eggs to settle and repeating the process until all of the lighter débris has been removed; or, in the case of urine, by simply diluting the specimen with 10 or more parts of water. The eggs usually hatch over night and the miracidia are found to be swimming about in the water next morning. The miracidia of *S. japonicum* collect in the uppermost portion of the water; those of *S. hæmatobium* are equally distributed throughout the medium. Faust and Meleney (1924) have advocated this hatching technique as a simple method for determining the presence of small numbers of *Schistosoma japonicum* eggs in fecal samples.

Eggs of *Clonorchis*, *Opisthorchis*, *Metagonimus*, *Heterophyes* and *Dicrocœlium* as well as those of *Tænia*, *Dipylidium* and *Hymenolepis* species, although fully embryonated when recovered from the feces, apparently hatch normally only after they have been ingested by the suitable intermediate host. Eggs of *Fasciola*, *Fasciolopsis*, echinostome species, *Paragonimus* and *Diphyllobothrium*, after being evacuated in the feces, mature in water. Development takes place most rapidly and the best yields of fully embryonated eggs are secured in shallow cultures at temperatures ranging from 20° to 30° C. Eggs of these species at the bottom of deep cultures develop very poorly. The available oxygen supply is apparently an important factor governing their development.

The Baermann Apparatus and Its Use.—This apparatus was originally devised for the isolation of hookworm larvæ from the soil. It is equally applicable for use in extracting other nematode larvæ from the soil as well as nematode larvæ from the feces and larvæ hatched from eggs in cultured feces. It depends on the principle that a large proportion of nematode larvæ will migrate out of soil into water of a somewhat warmer temperature which is brought in contact with the lower surface of the soil. In practice a

glass filter funnel of 15 to 23 cm. diameter is placed in a convenient rack or support. A rubber tube which is provided with pinch-cock or clamps is attached to the stem of the funnel. A wire basket of 1 mm. mesh copper or brass screening, with a diameter of 10 to 18 cm. and a height of 5 to 7.5 cm. is lined with coarse cloth and fitted into the funnel. The sample to be examined is comminuted and is then placed in the wire basket, the height of the luke-warm water, which has previously been introduced into the funnel, being adjusted so that it will just reach above the bottom of the sample in the basket. If a piece of ice is then placed on top of the sample the temperature differences between top and bottom will be greater and the movement of the larvæ downward into the water will be more rapid. Usually within ten or fifteen minutes they will be observed migrating into the stem of the funnel. After about one hour the maximum number has collected in the lower part of the stem. The clamp is opened and about 50 cc. of the water is run off into a centrifuge tube. The draw-off is then centrifuged, the supernatant water pipetted off and the sediment spread on a fecal slide for examination. Finely particulate soils may require a longer period of time for the migration of the larvæ. If too much of the soil particles is present in the run-off it may be necessary to utilize a small Baermann apparatus for a more careful separation of larvæ from these particles. It is also sometimes necessary to repeat the process once or twice in order to obtain the maximum yield. This technique following the culturing of the eggs may be used as a substitute for either the Lane direct centrifugal floatation or the Stoll egg-count method in estimating the number of hookworm eggs in a weighed fecal sample. However, it requires considerable time in order to allow the eggs to develop fully and the larvæ to hatch out. Its most useful application consists in providing a method for the accurate determination of the numbers of larvæ in the soil.

6. SEROLOGICAL DIAGNOSIS OF HELMINTHIC INFECTIONS.

It is desirable wherever possible to diagnose helminthic infections from the worms themselves or their reproductive products, eggs and larvæ. Under certain conditions, however, this is impossible except at operation or necropsy. In circumstances such as these sero-diagnostic methods may at times be utilized to advantage.

Serological and related reactions depend on the development in the body of a host-organism of specific antagonistic powers to an invading organism. In helminthic infections those species of worms which are intimately associated with the host tissues, so that their by-products become diffused throughout the body, are the ones which are most readily diagnosed by serological methods. Thus the species of *Schistosoma, Echinococcus* and *Trichinella* give a

positive serological test in a very high percentage of cases, while most helminths of the intestinal tract, as well as certain of the trematodes resident in the biliary passages, give consistently negative or uncertain tests. In the case of *Ascaris lumbricoides* the worm need not be an actual parasite, since emanations of this worm, as well as of the related species, *A. megalocephala*, have been found to sensitize certain persons handling or examining such specimens. There is no unanimity of opinion as to the nature of the by-product of the helminth which is responsible for the sensitization, but most workers believe that it is a protein, probably a globulin, with or without serum albumin.

The three types of reaction which have been obtained in the case of one or more of the human helminths are (1) complement-fixation (= complement deviation of N. H. Fairley), (2) flocculation, precipitation and precipitin reaction and (3) intradermal reaction.

1. **Complement-fixation.**—This test has been employed in practical diagnosis with positive results for the schistosomiases, paragonimiasis, hydatid cyst, and trichinosis. LeBas (1924) has found it negative in *Diphyllobothrium latum* infection and the present author has obtained negative results in clonorchiasis. The technique is on the whole similar to that of the Wassermann test for syphilis.

(*a*) **Schistosomiases.**—In *Schistosoma* infections the antigen may be prepared either from adult worms removed from human or reservoir hosts, or from the livers of snails containing the infection. Fairley (1919) has found that the intra-molluscan phase of the organism of either *S. hæmatobium* or *S. mansoni* serves satisfactorily as antigen in testing the serum from patients harboring either of these two species of blood flukes. Similar reciprocal use of antigen has apparently not been tried with *S. japonicum*. Both Yoshimoto (1910) and Fairley (1919) extracted the antigen with absolute alcohol, but LeBas (1922) considers that this is actually absolute alcohol diluted with physiological saline and has found that physiological saline alone is more satisfactory as a solvent for the antigen. The solution is centrifuged and is then used either directly by diluting with 4 parts of physiological saline or is first desiccated and then redissolved in 0.85 per cent NaCl solution. If kept in a tightly-stoppered bottle in a refrigerator the stock solution remains potent for two months.

Yoshimoto's Technique.—*Antigen* consists in an "alcoholic extract" of macerated adult *Schistosoma japonicum* obtained from autopsy of an infected reservoir host, using twenty times the volume of alcohol and extracting for twenty-four hours, then centrifuging until clear. The centrifugate serves as a stock solution; *antiserum* is prepared from serum of patients, inactivated for one-half hour at 56° C. and used undiluted; *complement* is fresh guinea-pig's serum, diluted just before using with 10 parts 0.85 per cent NaCl solution; *hemolysin* is inactivated serum of rabbits that had received at

intervals of seven days, 3 to 4 intravenous injections (5 cc. each) of a 5 per cent suspension of goat's blood corpuscles in 0.85 per cent NaCl solution, the serum being diluted 1 to 2.5 before using. After distributing the diluted antigen, in amounts 0.2 to 0.4 cc. in a series of sterilized tubes, the serum to be tested is added in doses of 0.2 cc. After adding to each tube 0.2 cc. of the freshly diluted complement the tubes are shaken thoroughly and placed for one hour in a water-bath at 37° C.; then 0.2 cc. of the diluted hemolysin is added together with 1 cc. of a 2.5 per cent suspension of washed goat's red corpuscles. The tubes are placed in the water-bath again for two hours, and are left in a cold place until next day, when readings are taken.

Fairley's Technique.—Antigen consists in the "alcoholic extract" of macerated snails infected with *Schistosoma hæmatobium* or *S. mansoni*, stored for twenty-four hours at 37° C., then filtered and the filtrate evaporated at 45° C. by means of an exhaust pump, the residue being dried, weighed and dissolved in 0.85 per cent NaCl solution (0.05 gm. residue to 20 cc. solution). *Antiserum, complement*, and *hemolysin* are prepared as in the Wassermann technique and the subsequent procedure is similar to that for the Wassermann reaction. Fairley (l. c.) states that pooled positive sera collected from early cases of schistosomiasis fix 7 minimum hemolytic doses of complement over and above that fixed by pooled negative sera in the presence of specific antigen, while in the older, more chronic cases, this excess fixation amounts to about 4 M. H. D. of complement. Yoshimoto found the fresh sera of schistosomiasis japonica cases to be strongly positive, while non-specific sera were negative or only faintly positive with schistosomiasis antigen.

The sero-diagnosis method is particularly valuable in suspected cases of schistosomiasis during the latter part of the incubation period before the eggs are produced and in chronic cases where the walls of the intestine and bladder have become so fibrosed that eggs cannot pass from the mesenteric veins or vesical plexuses into the lumen of these organs.

(*b*) **Paragonimiasis.**—The test, as worked out by Ando, is similar to that for schistosomiasis, the antigen being prepared by saline extracting from macerated adult *Paragonimus westermani* taken from a human infection at biopsy or autopsy or from experimental infections in reservoir hosts. The serological test is particularly useful in suspected cases of non-pulmonary paragonimiasis, where the worms are lodged in deep foci which do not permit the eggs to be evacuated in the excreta or through cutaneous lesions.

(*c*) **Echinococcus Infection.**—In this infection antigen consists of hydatid fluid removed aseptically from previous human cases or from infested mammalian reservoir hosts, preferably from infection in sheep with viable scolices (N. H. Fairley, 1922). The test is specific. Except in heavily endemic areas it is frequently difficult to obtain fresh antigen. Purulent or turbid hydatid fluid cannot be

used. On the whole the intradermal test (Casoni test) is much simpler and yields much more satisfactory results.

(*d*) **Tænia Saginata.**—Meyer (1910) has obtained complement-fixation in persons harboring the beef tapeworm.

(*e*) **Trichinosis.**—For sero-diagnosis of this infection Ströbel (1911) found that trichinized flesh digested in a culture chamber for twenty-four hours with caustic soda and antiformin, and later neutralized with hydrochloric acid and filtered, provides a reliable antigen which is potent for fourteen days if kept in a refrigerator. Alcoholic extract of trichinized flesh is said to give a negative reaction. 0.4 cc. of the antiformin extract has given a consistently positive reaction when known cases of trichinized individuals were tested, whereas a negative reaction was obtained with serum from a Wassermann-positive case.

(*f*) **Ascariasis.**—Antigen may be prepared by extracting in physiological saline solution the macerated adult worms which have been evacuated from human or porcine infections, then filtering and desiccating the solute. The fact that the serum of *Ascaris*-infected individuals gives a positive reaction is of little but academic interest where female worms are present, since eggs are so readily obtained for diagnosis, but in purely male infections it has a definite use.

(*g*) **Ancylostomiasis.**—The technique for preparation of the antigen is similar to that in *Ascaris* infection. The practical value of the test is also negligible except in purely male infection.

2. **Flocculation, Precipitation and Precipitin Reactions.**—These reactions are brought about most readily when the globulins of positive sera are brought in contact with various colloids, such as cholesterin, which in practice is added to the antigen preparation. Joffick, working in collaboration with Faust and Meleney (1924), utilizing a modified Sachs-Georgi test (Joffick, 1923), found, that in the case of animals positive for *Schistosoma japonicum*, heavy flocculation was obtained when 1 per cent alcoholic extract of cholesterin was added (1 unit as determined by titration per unit of diluted extract) to antigen prepared either from macerated adult *Schistosoma* worms or livers of *Schistosoma* infected snails, whereas negative sera failed to give flocculation, producing at most a slight opalescence.

A more simple technique, the Sia quantitative globulin precipitation reaction (Sia, 1924), has been tested by Faust and Meleney (1924) on cases of *Schistosoma japonicum* infection. The test is due to an excess of serum globulin in positive cases (50 to 200 per cent over normal sera) but is not entirely specific, since the reaction is also obtained in kala azar and leprous cases, and occasionally in malaria. Twenty cubic millimeters of the patient's blood, drawn into a Sahli hemoglobin pipette, is expelled into a small test-tube containing 0.6 cc. of distilled water and gently agitated until the two parts are mixed. The tube is observed at once and at intervals of

fifteen minutes, up to one hour. An immediate clouding of the water indicates a positive test. Sedimentation of the flocculent precipitate within fifteen minutes indicates a ++++ reaction; within thirty minutes, a +++ reaction; within forty-five minutes, a ++ reaction; and in one hour or longer, a + reaction.

The blood-serum aldehyde test, originally devised by Fox and Mackie (1921) and Napier (1922) for kala azar, is also usually positive in cases of schistosomiasis.

Echinococcus Infection.—This precipitin reaction, which has been particularly studied by Australian investigators, closely parallels the complement-fixation reaction. In practice fresh hydatid fluid is obtained aseptically from infested sheep. It is preserved by the addition of phenol solution and will remain stable for several months. 0.4 cc. of patient's fresh serum is added to an equal amount of the antigen in small agglutination tubes and allowed to stand for thirty-six hours at room temperature. In a serum with high precipitin-content (*e. g.*, high serum globulin) a precipitate forms in two or three hours. Thick flocculation has been designated as +++; fine precipitate with granules in suspension, ++; and microscopic granularity, +.

3. **Intradermal Reaction.**—This test consists in the injection intradermally of extract of parasite tissue or of fluid elaborated by the parasite, or in placing desiccated powdered tissue of the parasite on the skin which has been previously scarified. In sensitized individuals there is an immediate local reaction, consisting of an erythematous wheal which rapidly increases in size and tends to extend by pseudopodial runners until it reaches a maximum size in fifteen to twenty minutes, and begins to fade within an hour. There is usually also a delayed reaction some hours later, consisting of an area of erythema and induration around the site of injection or application of the antigen.

(*a*) **Echinococcus Infection.**—*The Casoni Reaction.*—The phenomenon of skin sensitiveness in echinococcus-positive individuals was first noticed by Casoni (1911), who obtained a proportion of positive reactions in cases of hydatid infection. Testi and Zoli (1919) and Dew, Kellaway and Williams (1925) have refined the test and studied the nature of its reaction. The Australian investigators have discovered that the immediate rather than the delayed reaction is the true index of sensitivity and have now almost consistently positive immediate reactions in positive cases, where the delayed reaction may be negative or doubtful and where the complement-fixation test is only positive in a proportion of the cases.

Technique.—The antigen, in the form of hydatid fluid, is obtained by aseptic puncture of hydatid cysts from the lungs and liver of sheep, oxen, pigs or human cases. Fluid from cysts showing degeneration or infection or that contaminated with blood or serum is discarded. Several samples are pooled to obtain uniform fluid, which

is then filtered, incubated to insure sterility and placed in sealed ampules on ice, where it has been found to retain its potency for six months. In carrying out the test on a suspected case the skin of the arm above the elbow is sterilized with alcohol and 0.2 cc. of the antigen is injected intradermally. A control injection of an equal amount of physiological saline solution is made several centimeters from the first injection. The wheal formed by the control fades while that produced by the hydatid fluid in positive cases develops almost immediately into the typical wheal characteristic of the reaction. The test is particularly valuable in preoperative cases and the reaction is immediately positive even in infections where operation showed the cyst to be suppurative and degenerate. In the latter type, as well as in recurrent cases, delayed reactions and complement-fixation are commonly negative. In postoperative cured cases intense skin reactions, including the delayed reaction, are obtained up to sixteen years, possibly due to considerable leakage of hydatid fluid at the time of operation.

(*b*) **Ascariasis.**—The test consists in placing a few drops of body fluid of *Ascaris lumbricoides* on a scarified area of the skin. In sensitized individuals there is an immediate local reaction, consisting of an erythematous wheal at the site of application, and frequently extensive lymphatic and systemic involvement. The more alarming symptoms disappear in the course of an hour or two but generalized edema may persist for some days. It is important to note that *Ascaris*-sensitization does not necessarily mean infection with *Ascaris* at the time of the test, but may be the result of a previous infection or, in the case of workers in a laboratory, merely contact with fresh or preserved worms (Ransom, Harrison and Couch, 1924).

(*c*) **Strongyloidiasis.**—The application of powdered *Strongyloides* to a scarified area of the skin produces in a few minutes an urticarial wheal in animals positive for this worm, even in cases of very light infection which require culture methods for diagnosis (Fülleborn, 1926).

(*d*) **Loaiasis.**—It has been suggested by Schilling (1926) that Calabar swellings in *Loa loa* infections may be explained on the same basis as the intradermal reaction. Fülleborn (1926) apparently concurs in this view.

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Consult the main body of this book and the references cited at the conclusion of each chapter.

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CHAPTER XXXIV.

INTERMEDIATE AND RESERVOIR HOSTS INVOLVED IN HUMAN HELMINTHIC INFECTIONS.

Introduction.—Perusal of the foregoing sections of this volume will indicate the considerable number of invertebrate and vertebrate animals which serve as intermediate hosts of human helminthic infections. In some cases, such as some of the tapeworm and many of the nematode infections, and also the blood flukes of the trematode group, there is only one intermediate host. In other cases there are two successive intermediate hosts required before the organism is ready to enter the definitive host. In the former case without exception the intermediate host is always an invertebrate. In the latter case the first intermediate host is always an invertebrate animal, but the second intermediate host is in some instances an invertebrate animal and in other instances a vertebrate. It has seemed desirable to collect the information regarding the respective intermediate hosts involved in these infections and present it in brief systematic form, so that the reader will have some idea of the taxonomic relationships of such hosts. In practically no case has it been possible to give sufficient information for the student of helminthology to determine the species of organism involved in this host capacity. For this purpose special monographs on the groups or subgroups should be consulted, or, better, specialists in these groups should be called upon to diagnose the host species. A number of representative illustrations has been provided to help the student who is not familiar with the invertebrate groups to recognize at least the family and in some cases the generic characteristics of these organisms. The vertebrate forms are so much more diversified that it has not seemed wise to provide similar illustrations for them.

INVERTEBRATE INTERMEDIATE HOSTS.

The invertebrate animals serving as intermediate hosts belong to two large phyla of the **Animal Kingdom**, the **Arthropoda** (insects and their allies) and the **Mollusca** (snails *et al.*). The vertebrate hosts include representatives of the phyla **Pisces** (fishes), **Amphibia** (frogs) and **Reptilia** (snakes), and in a few isolated instances, **Aves** (birds) and **Mammalia** (mammals).

I. **The Arthropoda.**—The arthropoda are bilaterally symmetrically metazoa, with a well-developed body cavity, segmented body, and with articulated segmented appendages which are penetrated by blood spaces, and which are differentiated at the anterior end of the body to form grasping, biting or sucking organs. The classes of this phylum which serve as intermediate hosts of helminthic infections are the **Crustacea, Insecta** and **Myriapoda.**

Class **CRUSTACEA** Lamarck, 1815. This class of invertebrates consists of forms having typically 2 pairs of preoral antenniform appendages and at least 3 pairs of postoral appendages acting as jaws. They are chiefly aquatic and breathe entirely through gills. They are divided into two large subclasses, the **Entomostraca** and the **Malacostraca.** Both of these groups contain important intermediate hosts of human helminths.

Subclass **Entomostraca** Mueller, 1785. This is a large group of small Crustacea, which are fresh-water or marine species, free-living or parasitic in habits, and are usually considered of economic importance because they constitute the essential food supply of many food fishes of man. Of the three recognized orders (**Phyllopoda** Latreille, 1802, **Ostracoda** Latreille, 1802 and **Copepoda** Milne-Edwards, 1840), members of each serve as intermediate hosts of cestode infections of higher vertebrates, while the **Copepoda** are also involved as intermediate hosts of the Medina worm, *Fuellebornius medinensis.* Only the **Copepoda** are concerned in human cestode infections. The larvæ enter the digestive tract of the crustacean host passively, penetrate its intestinal wall and develop in its body cavity.

Order **COPEPODA** Milne-Edwards, 1840. These are forms in which the body lacks a carapace; they consist of both free-living and parasitic species, the former being elongate, segmented and having cylindrical thoracic appendages; also possessing 1 pair of maxillæ and 4 to 5 pairs of biramous legs. Two suborders, **Eucopepoda** Claus, 1875, and **Branchiura** Burmeister, 1834, are recognized. Only species of the former group have been found to harbor human helminth larvæ.

Suborder **Eucopepoda** Claus, 1875. Females of this group carry egg-sacs. Compound eyes are lacking. The free-swimming forms are all included in the **Gnathostomata** Claus, 1885, which have mouth-parts adapted to chewing and have normal body segments. Two families of this subgroup are involved in human helminthic infections, the **Diaptomidæ** Sars, 1897, and the **Cyclopidæ** Burmeister, 1834.

Family *DIAPTOMIDÆ* Sars, 1897. The first pair of antennæ is long, commonly about as long as the body, and composed of 23 to 25 segments in females. The antennæ of the males are asymmetrical, the right being geniculate and modified as a grasping organ. Of the many recognized species of the type genus *Diaptomus* (Fig. 265) the following have been found to serve as intermediate hosts of human tapeworm infections.

Diaptomus gracilis Sars, 1862. First intermediate host of *Diphyllobothrium latum* in Europe (Janicki and Rosen, 1917).

D. oregonensis Lilljeborg, 1889. First intermediate host of *D. latum*, Minnesota, U. S. A. (Essex, 1927).

D. spinosus "Daday." Intermediate host of *Drepanidotænia lanceolata* in Europe (Daday, 1900).

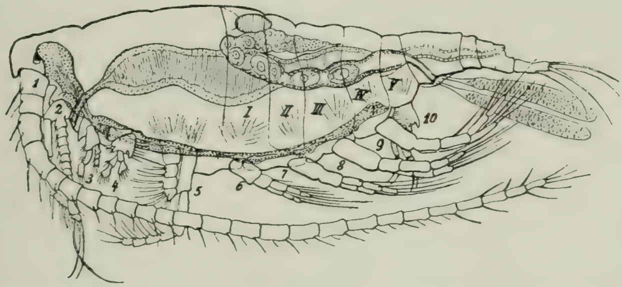

FIG. 265.—*Diaptomus castor.* (After Kingsley, Courtesy of Henry Holt & Co.)

Family *CYCLOPIDÆ* Burmeister, 1834. The first pair of antennæ is 6- to 17-segmented, never being shorter than the cephalothorax. The antennæ of the males are symmetrically geniculate. The fifth feet are rudimentary, 1 to 3 segmented. The females carry two egg-sacs. The type genus, *Cyclops* (Fig. 266), is a very important intermediate host of species of *Diphyllobothrium* and of *Fuellebornius medinensis.* Classification of the species of *Cyclops* is based on the number of segments of the antennæ of the females, the structure of the furcal rami of the abdomen, and the structure of the fifth foot.

Cyclops bicuspidatus Claus, 1857. Intermediate host of *Fuellebornius medinensis.* Europe (?).

Cyclops coronatus Claus, 1857 (?). Intermediate host of *F. medinensis.* Europe (?).

Cyclops leuckarti Claus, 1857. First intermediate host of *Diphyllobothrium "mansoni"* in the Far East (Okumura).

Cyclops prasinus Jurine, 1820. First intermediate host of *D. latum* in Minnesota, U. S. A. (Essex, 1927); intermediate host of *F. medinensis,* with incomplete development.

Cyclops serratus Pratz, 1866. Intermediate host of *Drepanidotænia laceolata* in Europe (Mrazek, 1890).

Cyclops serrulatus Fischer, 1851. Intermediate host of *D. lanceolata* in Europe (Mrazek, 1890).

Cyclops strenuus Fischer, 1851. First intermediate host of *D. latum* in Europe (Rosen and Janicki, 1917).

Cyclops viridis Jurine, 1820 (= *C. quadricornis* Linn., 1758, *pro parte?*). Incomplete development of *F. medinensis*. *C. viridis* var. *brevispinosus*, first intermediate host of *D. latum* in Minnesota, U. S. A. (Essex, 1927).

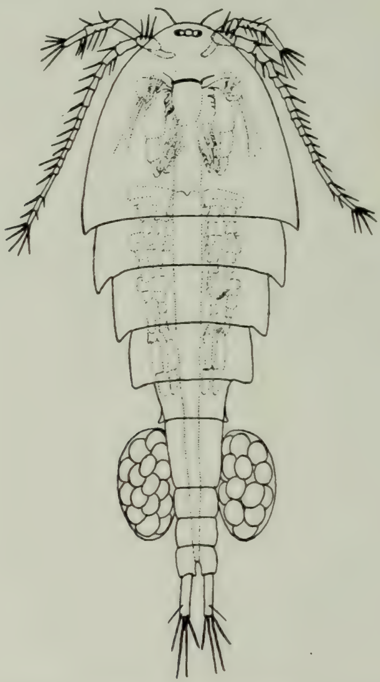

FIG. 266.—*Cyclops coronatus*, female, dorsal view. (Original.)

Subclass **Malacostraca** Latreille, 1802. This is an extensive group of the larger Crustacea, which usually possess abdominal appendages. They typically have 20 segments, 5 in the head, 8 in the thorax, and 7 in the abdomen, of which those in the thorax and abdomen are distinct. There are typically 19 pairs of appendages (5 cephalic, 8 thoracic and 6 abdominal). The division **Thoracostraca** Burmeister, 1834, contains the

Order **DECAPODA** Latreille, 1802, which is characterized by having a carapace covering all of the thorax, and includes all of

the species of the group which are involved as intermediate hosts of human helminths. These species are commonly referred to as crayfishes, lobsters and crabs. In endemic areas in the Orient they live in more or less close association with the molluscan first intermediate host of *Paragonimus westermani* (various species of *Melania*). The cercariæ of the fluke encyst in the soft tissues of the crustacean, including the gills, liver and muscles. Mammalian infection is contracted almost exclusively from eating the raw tissues of the crustacean host.

The crayfishes and lobsters belong to the

Tribe ASTACIDIA Dana, 1852, and are characterized by having a carapace free from the epistome and a rostrum of good size. The abdomen extends normally as a subcylindrical portion behind the thorax. They are grouped in two families.

Family *HOMARIDÆ* Bate, 1888. This group contains the lobsters, which are marine forms and do not harbor human helminth infections.

Family *ASTACIDÆ* Dana, 1852. This group contains the crayfishes which are fresh-water forms. Two species of the type genus are involved in *Paragonimus westermani* infection in Japan and Korea.

Astacus (*Cambaroides*) *japonicus* de Haan, 1842. Second intermediate host of *Paragonimus westermani* in Japan. (See Fig. 116*A*.)

Astacus (*Cambaroides*) *similis* Koelbel, 1892. Second intermediate host of *P. westermani* in Korea.

The crabs belong to the

Tribe BRACHYURA Leach, 1813, and are characterized by having a flat body, a short abdomen, tail usually bent under the thorax, and a carapace fused with the epistome. The fresh-water species involved in *Paragonimus westermani* infection belong to the families **Potamonidæ** Ortmann, 1896 and the **Grapsidæ** Dana, 1851.

Family *POTAMONIDÆ* Ortmann, 1896. These are fresh-water crabs with a highly-developed and swollen branchial region, and usually with a squarish body.

Potamon (*Geothelphusa*) *dehaani* (White, 1847). This is a small species living in the hill streams, ponds and irrigation ditches of Japan and Formosa; reported from China but not incriminated in *Paragonimus* infection in that country. Involved as the most important second intermediate host of *Paragonimus westermani* in endemic countries (Yoshida, Miyairi, Yokogawa, Kobayashi).

Potamon (*Geothelphusa*) *obtusipes* (Stimpson, 1858). This species is found in the mountain streams of Formosa, and has been reported

from Manila and Bengal. Second intermediate host of *P. westermani* in Formosa (Nakagawa, 1915–1919).

Parathelphusa (*Parathelphusa*) *sinensis* (Milne-Edwards, 1853). This species is common in the coastal fresh-waters in China, French Indo-China, Siam and Burma, and is believed to be the second intermediate host of *Paragonimus* in reservoir hosts in those countries.

Pseudothelphusa iturbei Rathbun, 1919. This species is the second intermediate host of *Paragonimus* in Venezuela, where it lives in the mountain streams (Iturbe, 1919).

Family *GRAPSIDÆ* Dana, 1851. These are fresh-water crabs having straight or only slightly arched sides. The shape of the body is squarish or squarish-oval.

Eliocheir japonicus (de Haan, 1850). This species is the common edible crab in Japan. It is also found in Formosa and Korea. In Japan it is the second most common source of human infection with *Paragonimus* (Yoshida).

Eliocheir sinensis (Milne-Edwards, 1853). This species has been reported from Japan and the lower Yangtze drainage. It is a minor second intermediate host of *Paragonimus*.

Sesarma (*Holometropus*) *dehaani* Milne-Edwards, 1853. This species, which lives in the lower parts of the rivers of Japan and China and is at times found in brackish waters, is not a food crab, but has been found experimentally to be a possible source of *Paragonimus* infection (Yoshida, 1916).

Class **INSECTA** Linnæus, 1758. This group contains those Arthropoda which have three pairs of thoracic legs and usually two pairs of wings on the thorax, which is composed of three segments. They breathe by means of tracheæ. The abdomen is composed typically of ten segments, of which the terminal one is modified for sexual purposes.

Order **DIPTERA** Linnæus, 1758. (Flies.) The species of this order have one pair of transparent wings and a pair of rudimentary wings (halteres or balancers). The mouth parts are adapted to piercing or to sucking. The metamorphosis is complete. Of the three suborders, intermediate hosts of human helminths all belong to the

Suborder **Orthorrhapha.** The flies of this group lack a lunula or ptilinum. The larvæ have a distinct head. The pupæ are obtectate. The imagos (adults) escape from the pupal cases through a T-shaped opening. Most of the species of interest to students of human helminthology belong to the section **Nematocera**, but at least one species of the section **Brachycera** is also involved as an intermediate host of helminth infections.

Section Nematocera Latreille, 1825. These forms have long antennæ, composed of more than 6 segments, with all but the first two proximal ones similar. There is no arista. The discal cell of the wing is usually absent and the anal cell widely open at the margin. Three families of this group are involved in human helminthic infections, the **Culicidæ**, the **Chironomidæ** and the **Simuliidæ**.

Family *CULICIDÆ* Stephens, 1829. (Mosquitoes.) These species have a long piercing proboscis and a body more or less clothed with scales or hairs. The antennæ are provided with hairs in whorls, which are dense in the males and scanty in the females. The wings have six or seven longitudinal veins, with two distinct fork cells but never with two distinct anal veins or a discal cell. The costa passes around the wing and is clothed with a fringe of scales. There are two recognized tribes of the subfamily **Culicinæ** Theobald, 1901, which concern helminthologists, the **Anophelini** and the **Culicini**.

Tribe Anophelini. These mosquitoes have the palps of both sexes as long as the proboscis, the terminal joints of the male palpi often being thickened. The apical joint terminates bluntly. The thorax is elongate and cylindrical, rarely rounded. The posterior (free) edge of the scutellum is evenly rounded. The abdomen is not densely invested with overlapping scales. The larvæ lack an air-siphon but have a conspicuous stigmal plate. Palmate hairs are usually present on the dorsal surface of the abdominal segments. When at rest the bodies of the larvæ lie parallel to the surface film. When feeding the head is rotated through an arc of 180 degrees. The following species of the type genus *Anopheles* are involved in human helminthic infections.

Anopheles (*Anopheles*) *algeriensis* Theobald, 1903. Intermediate host of *Wuchereria bancrofti*. Distribution, Mediterranean littoral, Macedonia, Mesopotamia.

A. (*Anopheles*) *bifurcatus* (Linnæus, 1758) Meigen, 1818. Partial development of *W. bancrofti*. Distribution, Nearctic.

A. (*Anopheles*) *hyrcanus* Pallas, 1771. Partial development of *W. bancrofti*. Distribution, Palearctic and Oriental.

A. (*Anopheles*) *maculipennis* Meigen, 1818. Partial development of *W. bancrofti*, *Acanthocheilonema perstans* and *Mansonella ozzardi*. Distribution, Palearctic and Mediterranean littoral.

A. (*Cyclolepteron*) *intermedius* Chagas, 1908. Partial development of *W. bancrofti*. Distribution, Brazil.

A. (*Myzomyia*) *costalis* Loew, 1866. Complete development of *W. bancrofti;* partial development of *A. perstans*. Distribution, Eastern Coast of Africa, India, Southern China.

A. (*Myzomyia*) *rossi* Giles, 1899. Complete development of *W. bancrofti*. Distribution, Oriental.

A. (*Myzomyia*) *vanus* Walker, 1860. Complete development of *W. bancrofti*. Distribution, Oriental.

A. (*Myzorhynchus*) *barbirostris* Van der Wulp, 1884. Partial development of *W. bancrofti*. Distribution, East African, Oriental, Australian.

A. (*Myzorhynchus*) *nigerrimus* Giles, 1900. Complete development of *W. bancrofti*. Distribution, India.

A. (*Myzorhynchus*) *peditæniatus* Leicester, 1908. Complete (?) development of *W. bancrofti*.

A. (*Nyssorhynchus*) *albimanus* Wiedemann, 1821. Complete development of *W. bancrofti*. Distribution, Neotropical.

A. (*Nyssorhynchus*) *annulipes* Walker, 1850. Partial development of *W. bancrofti*. Distribution, Australia to Formosa.

A. (*Nyssorhynchus*) *argyritarsis* Rob.-Desv., 1827. Partial development of *W. bancrofti*. Distribution, Neotropical.

Tribe CULICINI. These mosquitoes have the palps of the females shorter than the proboscis, while those of the males are usually as long or much longer than the proboscis. The terminal joints of the palps are often upturned and clothed with long hairs. The apical joint is usually tapering and pointed. The thorax is rounded. The posterior (free) edge of the scutellum is trilobate, the central lobe being always distinct. The larvæ have a distinct air-siphon and lack palmate hairs on the dorsum of the abdominal segments. When at rest the larvæ hang at an angle with the surface film. The head is not rotated when feeding. The following species belonging to the genera *Culex*, *Ædes* and *Mansonia* are involved in human helminthic infections.

Culex fatigans Wiedemann, 1828. Complete development of *W. bancrofti*. Distribution, Oriental, Neotropical.

C. gelidus Theobald, 1901. Partial development of *W. bancrofti*. Distribution, Oriental.

C. pipiens Linnæus, 1758. Complete development of *W. bancrofti;* partial development of *A. perstans*. Distribution, Palearctic.

C. sitiens Wiedemann, 1828. Partial development of *W. bancrofti*. Distribution, Polynesia.

C. skusei Giles, 1900. Partial development of *W. bancrofti*. Distribution, Australasian.

Ædes (*Stegomyia*) *ægypti* (Linnæus, 1762) Dyar, 1922. Complete development of *W. bancrofti;* partial development of *A. perstans* and *M. ozzardi*. Distribution, Oriental and Nearctic.

A. (*Stegomyia*) *albolineatus* Theobald, 1904. Partial development of *W. bancrofti*. Distribution, Malaya.

A. (*Stegomyia*) *chemulpœnsis* Yamada, 1921. Partial development of *W. bancrofti*. Distribution, Korea.

A. (*Stegomyia*) *desmotes* Giles, 1904. Partial development of *W. bancrofti.* Distribution, Philippines.

A. (*Stegomyia*) *perplexus* Leicester, 1908. Partial development of *W. bancrofti.* Distribution, Malaya.

A. (*Stegomyia*) *scutellaris* Walker, 1859. Complete development of *W. bancrofti.* Distribution, Oriental and Australian.

A. (*Culicelsa*) *vigilax* Skuse, 1889. Partial development of *W. bancrofti.* Distribution, Australian.

A. (*Ochlerotatus*) *caspius* Pallas, 1771. Partial development of *W. bancrofti.* Distribution, Palæarctic.

A. (*Tæniorhynchus*) *domesticus* Leicester, 1908. Partial development of *W. bancrofti.* Distribution, Malaya.

A. (*Tæniorhynchus*) *tæniorhynchus* Wiedemann, 1821. Partial development of *W. bancrofti.*

A. esœnsis Yamada, 1921. Partial development of *W. bancrofti.* Distribution, Japan.

A. galliosi Yamada, 1921. Partial development of *W. bancrofti.* Distribution, Japan.

A. togoi Theobald, 1907. Complete (?) development of *W. bancrofti.* Distribution, Japan.

Mansonia (*Mansonioides*) *annulipes* Walker, 1857. Complete (?) development of *W. bancrofti.* Distribution, Ethiopian, Malaya.

M. (*Mansonioides*) *pseudotitillans* (Theobald, 1901) Blanchard, 1905. Complete development of *W. bancrofti.* Distribution, Neotropical, Oriental.

M. (*Mansonioides*) *uniformis* Theobald, 1901. (= *Panoplites africanus*). Complete (?) development of *W. bancrofti;* partial development of *A. perstans.* Distribution, Ethiopian, Oriental, Australian.

Family *CHIRONOMIDÆ* Westwood, 1840. (Midges.) The members of this very large family are small to medium-sized flies with a small head often concealed by the thorax. They have short palps with 2 to 5 segments, and antennæ consisting of 6 to 15 joints. The wings are narrowed and lack a vein along the posterior margin. The costal vein ends near the tip of the wing and the fourth and fifth veins are frequently forked. The early stages of the life cycle are passed in water or mud. Two species, *Culicoides austeni* and *C. grahami* are of importance in medical helminthology.

Culicoides austeni Carter, Ingram and Macfie, 1920. (Fig. 267.) Complete development of *Acanthocheilonema perstans,* with emergence of the mature larvæ from the proboscis, has been witnessed by Sharp (1928). Distribution, Ethiopian.

Culicoides grahami Austen, 1909. (Fig. 268.) Complete development of *Acanthocheilonema perstans* is believed to take place in this midge, which is a persistent and vicious biter. Distribution, Ethiopian.

FIG. 267.—*Culicoides austeni.* (After Jobling in Sharp, Trans. Royal Soc. Trop. Med. Hyg.)

FIG. 268

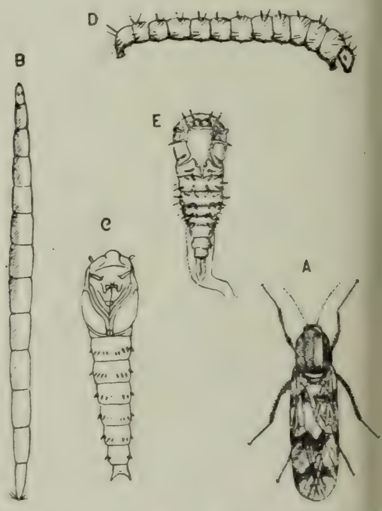

FIG. 269

FIG. 268.—*Culicoides grahami.* (After Carter in Byam and Archibald, Practice of Medicine in the Tropics.)

FIG. 269.—Larval types of *Culicoides: A*, imago, *B*, larva from water, *C*, pupa from water; *D*, larva from mud; *E*, pupa from mud. (After Johannsen, Courtesy of the New York State Museum, Albany, N. Y.)

Family *SIMULIIDÆ* Latreille, 1804. (Gnats, black-flies or buffalo-flies.) The members of this small family are small, robust, hump-backed flies, with short, straight antennæ, consisting of 11 joints and lacking long hairs. The palps are small and incurved. The wings are broad and relatively large and the legs are stout and large. Species of the genus *Simulium* are important as intermediate hosts of the filarioid nematode genus, *Onchocerca*.

FIG. 270.—*Simulium damnosum.* (After Carter in Byam and Archibald, Practice of Medicine in the Tropics.)

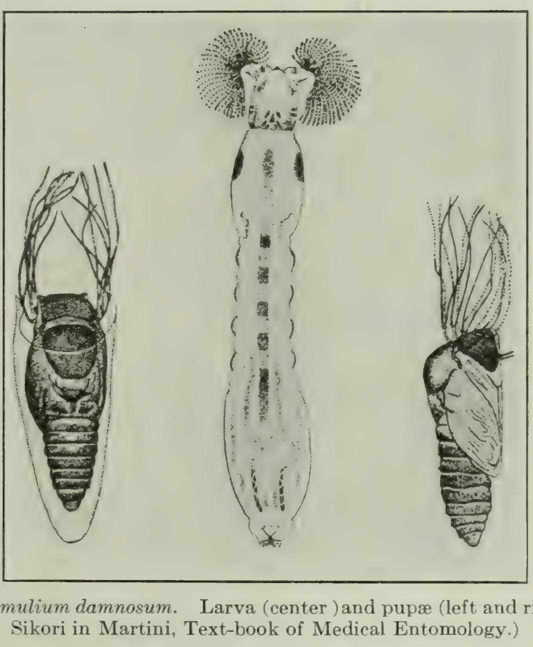

FIG. 271.—*Simulium damnosum.* Larva (center)and pupæ (left and right). (After Sikori in Martini, Text-book of Medical Entomology.)

Simulium damnosum Theobald, 1903. (Figs. 270 and 271.) Complete development of *Onchocerca volvulus* has been found to occur in this gnat, which frequents vegetation along river embankments. Distribution, Ethiopian.

Simulium sp. *Onchocerca cæcutiens* is believed to undergo larval development in a species of *Simulium* in Costa Rica.

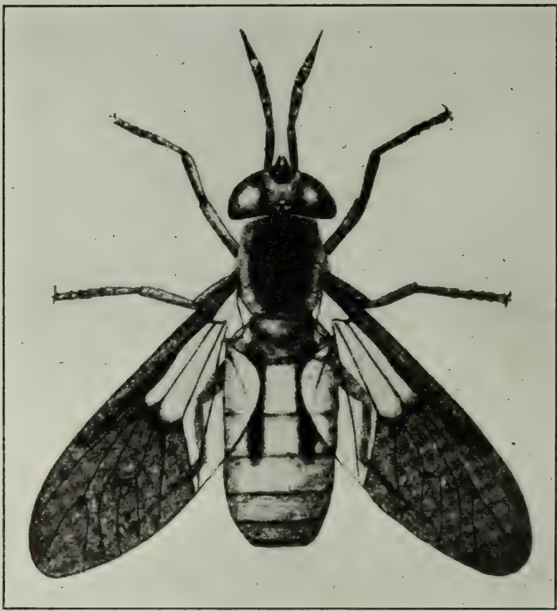

FIG. 272.—*Chrysops dimidiatus*. (After Grünberg in Martini, Text-book of Medical Entomology.)

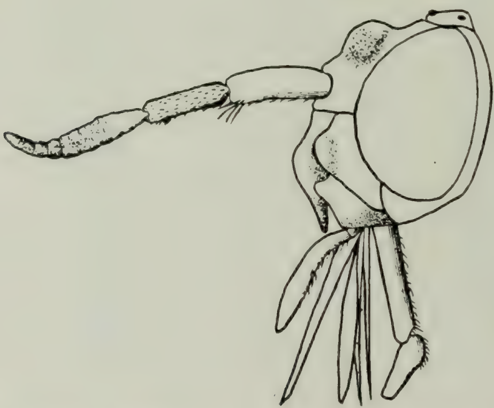

FIG. 273.—*Chrysops dimidiatus*. Profile of head of *Chrysops*. (After Surcouf and Gonzalez-Rincones, in Arch. de Parasitol., permission of Masson et Cie.)

Section BRACHYCERA HOMODACTYLA Macquart, 1834. Members of this group are characterized by having short antennæ with dis-

similar joints. The important family **Tabanidæ** is of great economic importance. The species of this family are commonly spoken of as "horse flies" or "gad flies."

Family *TABANIDÆ* Leach, 1819. These species are usually thick-set, bulky flies, with a head as wide or wider than the thorax, convex in front, with very large, brilliantly-colored eyes, which in the male almost meet but are a considerable distance apart in the female. The antennæ are 3-segmented, the last joint having from 4 to 8 annulations. There is no arista. Of the two subfamilies, **Tabaninæ** and **Pangoninæ**, members of the latter belonging to the genus *Chrysops* are important as intermediate hosts of the Loa worm.

Chrysops dimidiata (Van der Wulp, 1885). (Figs. 272 and 273.) Intermediate host of *Loa loa*. Distribution, Ethiopian.

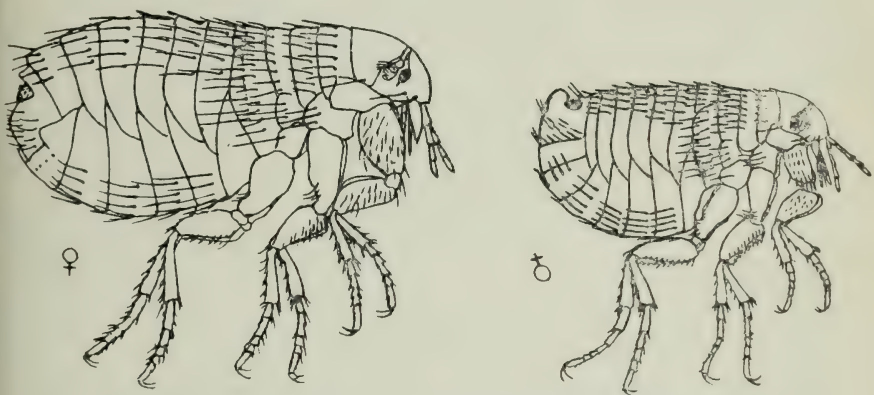

FIG. 274.—*Pulex irritans.* (After Castellani and Chalmers, Manual of Tropical Medicine.)

Chrysops silacea Austen, 1907. Intermediate host of *Loa loa*. Distribution, Ethiopian.

Order **SIPHONAPTERA** Latreille, 1825. (Fleas.) This order contains those insects which have laterally compressed bodies with distinctly separated thoracic rings. The wings are lacking except for two lateral plate-like structures on the mesothorax and metathorax. The mouth parts are adapted to piercing the skin and sucking blood. The antennæ are 3-jointed and are carried in a groove on either side of the head. Metamorphosis is complete. Of the several recognized families the **Pulicidæ** and the **Ceratophyllidæ** serve as intermediate hosts of human helminths.

Family *PULICIDÆ* Stephens, 1829. These species have a small head with rounded top. The abdomen is never so swollen as to lose its original contour. The venter is provided with hairs. Members of this family are never tissue parasites. The following

species are important as proven intermediate hosts of cestode infections of man:

Pulex irritans Linnæus, 1758. (The human flea, Fig. 274.) This species is commonly found on dogs, cats and at times rats. It

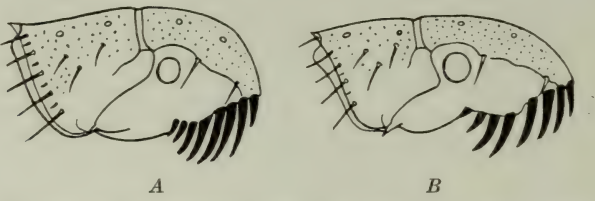

FIG. 275.—*A*, head of *Ctenocephalus canis; B*, head of *C. felis.* (After Alcock, Entomology for Medical Officers.)

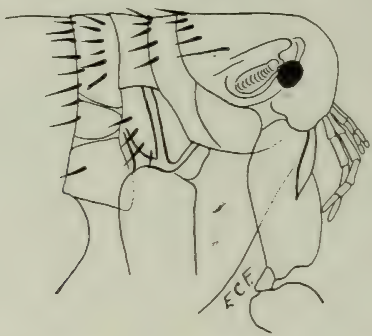

FIG. 276.—Head of *Xenopsylla cheopis.* (Original.)

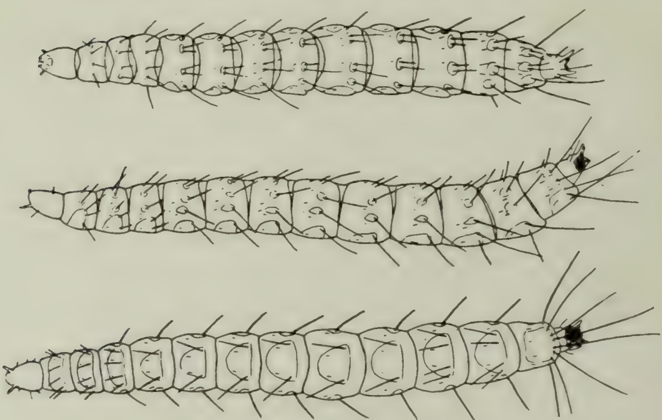

FIG. 277.—Larvæ of *X. cheopis.* (After Bacot and Ridewood in Martini, Text-book of Medical Entomology.)

serves as the intermediate host of *Dipylidium caninum* and possibly also of *Hymenolepis diminuta.* Distribution, Cosmopolitan.

Ctenocephalus canis Curtis, 1829. (The dog flea, Fig. 275 *A*.) Intermediate host of *D. caninum* and possibly of *H. diminuta*. Distribution, Cosmopolitan. The related species *C. felis* (Fig. 275 *B*), may also possibly serve in this capacity.

Xenopsylla cheopis Rothschild, 1903. (The rat flea of the temperate zone, Figs. 276 and 277.) Intermediate host of *H. diminuta*. Distribution, Palearctic.

Family *CERATOPHYLLIDÆ* Rothschild, 1915. In this family the head of the male is flattened on top. There are no spines on the head. There is always a comb of spines on the pronotum. There are three antepygidial bristles on each side of the female but frequently fewer in the male. One species, *Ceratophyllus fasciatus* (Bosc, 1800) (Fig. 278), is involved as an intermediate host of *H. diminuta*. Distribution, Tropical.

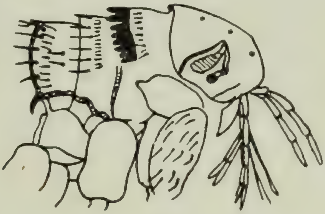

FIG. 278.—Head of *Ceratophyllus fasciatus*. (After Alcock, Entomology for Medical Officers.)

Order **ANUPLURA** Leach, 1815. (Sucking lice.) This order contains those insects with a proboscis consisting of a fused labrum and labium, armed with recurved hooklets, and containing a hollow extensile sucker formed by the mandibles and maxillæ, adapted for sucking. The antennæ are 5-jointed. The thorax is practically unsegmented and there are no wings. The legs have terminal claws adapted to clinging to the host. The last abdominal segment is rounded in the male and notched in the female. Metamorphosis is incomplete. These species must not be confused with the **Mallophaga**, which are biting forms ectoparasitic on birds and mammals. Members of this order, particularly *Pediculus humanus*, have been suspected of serving as intermediate hosts of *Dipylidium caninum* and other helminthic infections of man but substantial proof is lacking.

Order **MALLOPHAGA** Nitzsch, 1818. (Biting lice.) These insects are of small size and wingless, are provided with biting mouth parts and with well-developed mandibles. The legs are flattened and end in one or two claws. One species of the family

Trichodectidæ Burmeister, 1835, is involved as an intermediate host of *Dipylidium caninum*. This is *Trichodectes canis* de Geer, 1783, the common dog louse. (Fig. 279.) Distribution, Cosmopolitan.

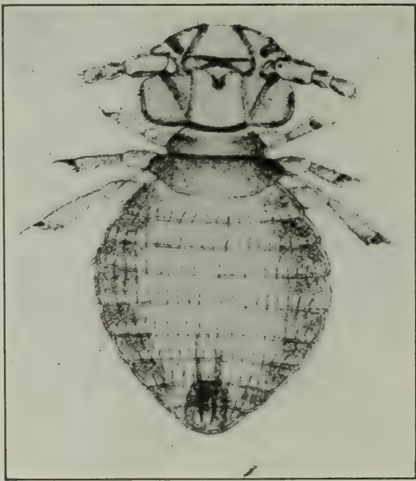

FIG. 279.—*Trichodectes canis*. (After Piaget.)

Order **LEPIDOPTERA** Linnæus, 1758. (Moths and butterflies.) This order comprises those forms which have two pairs of membranous expansive wings, clothed with scales. The mouth parts are adapted only to sucking. Metamorphosis is complete. *Asopia farinalis* (Linnæus, 1758), the "meal-worm," of the family **Pyralidæ**, Leach, 1819, in both its larval and adult state, is an intermediate host of *Hymenolepis diminuta*.

Order **ORTHOPTERA** Olivier, 1789 (?). (Grasshoppers, crickets, cockroaches, earwigs, etc.) This order consists of forms having the first pair of wings leathery in consistency and forming a covering over the second pair, which are membranous. The mouth parts are adapted to biting and chewing. There is no pupal stage.

The suborder **Saltatoria** contains those forms which have legs of unequal size, the hind femora being enlarged for leaping. They comprise the grasshoppers, locusts and crickets. Several species of this group are larval hosts of gordiacean worms, which are at times accidentally ingested by man.

The suborder **Cursoria** contains those forms which have legs of approximately equal size and not adapted to leaping. They comprise the cockroaches, praying insects and stick insects. The cockroaches are important intermediate hosts of certain helminthic infections.

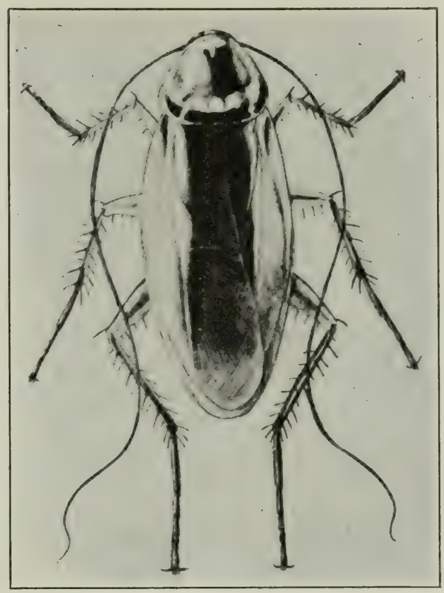

FIG. 280.—*Periplanata americana.* (After Marlatt, U. S. Department of Agriculture.)

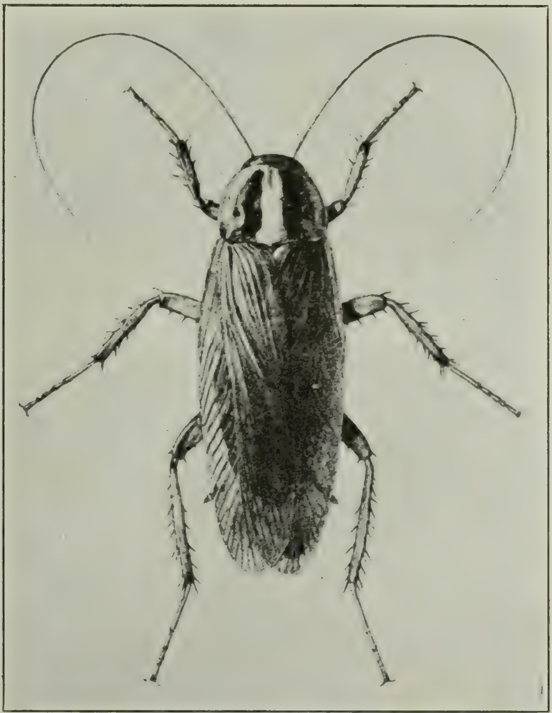

FIG. 281.—*Blatella germanica.* (After Terzi in Sambon, Journal of Tropical Medicine and Hygiene.)

Family *BLATTIDÆ* Stephens, 1829. (Cockroaches.) These species have a very large pronotum which often conceals the head. Their broad coxæ cover the ventral surface of the thorax and the base of the abdomen.

Periplanata americana (Linnæus, 1758). (Fig. 280.) Intermediate host of *Hymenolepis diminuta, Davainea madagascariensis* (?), *Gongylonema pulchrum,* and *Moniliformis moniliformis* (?) Distribution, typically Neotropical.

Blatella germanica (Linnæus, 1767). (Fig. 281.) Intermediate host of *Hymenolepis diminuta* and *Gongylonema pulchrum.* Distribution, European.

The suborder **Euplectoptera** (order **Dermaptera** of some authors) comprises elongate insects, having the forewings modified into very short leathery tegumenta and having the caudal cerci unjointed and usually modified into horny forceps. They are commonly called "earwigs." One species, *Anisolabis annulipes* Lucas, is the intermediate host of *Hymenolepis diminuta.*

Order **COLEOPTERA** Linnæus, 1758. (Beetles.) These are insect species which have the fore-wings modified into horny or leathery elytra which almost always meet to form a straight mid-dorsal suture and hind-wings either membranous and folded beneath the elytra or reduced or wanting. The mouth parts are adapted to biting. Metamorphosis is complete. The group is a very large one and comprises thousands of species. Several species are involved in human helminthic infections. All of these belong to the suborder **Polyphaga**.

Superfamily STAPHYLINOIDEA, family **Spæriidæ** MacLeay, 1825. These minute forms have non-geniculate antennæ, 3-jointed tarsi, and an abdomen with three sternal plates. A species of the type genus *Sphærius* is involved as an intermediate host of *Gongylonema pulchrum.*

Superfamily HETEROMERA, family **Tenebrionidæ** Leach, 1817. This is a very large family which is cosmopolitan in distribution, some species living in the ground, others in cellars and outbuildings, others boring in wood, others living in granaries, and still others living in dung, on dead animals, fungi, etc. The following species have been incriminated in human helminthic infections:

Akis spinosa (Linnæus, 1764). Intermediate host of *Hymenolepis diminuta.*

Blaps appendiculata Motsch., 1851. Intermediate host of *Gongylonema pulchrum.* (Other species of *Blaps* probably also serve in this capacity.)

Blaps mucronata Latreille, 1804. Intermediate host of *Moniliformis moniliformis.*

Scaurus striatus Fabricius, 1792. Intermediate host of *Hymenolepis diminuta.*

Tenebrio molitor Linnæus, 1758. Larva, intermediate host of *Hymenolepis diminuta.* Secures infection from rat-droppings in meal, etc.

Superfamily LAMELLICORNIA, family **Scarabæidæ** Leach, 1817. This extremely large family comprises those species having highly differentiated antennæ of a lamellate club type; body incapable of being rolled up; legs 5-jointed, the first pair being sometimes wanting. The elytra usually fail to cover the abdomen. The larvæ of a large portion of these species live in the ground, or feed on decaying vegetation or dung. The adults are frequently omnivorous.

Aphodius fimetarius (Linnæus, 1758). Intermediate host of *Gongylonema pulchrum.* Related species of the genus *Aphodius* also probably serve in this capacity.

Caccobius schreberi (Linnæus, 1758). Intermediate host of *G. pulchrum.*

Cetonia aurata (Linnæus, 1761). Intermediate host of *Macracanthorhynchus hirudinaceus.*

Diloboderus abderus Sturm, 1826. Intermediate host of *Macracanthorhynchus hirudinaceus.*

Gromphas lacordairei Brullé, 1834. Intermediate host of *Macracanthorhynchus hirudinaceus.*

Lachnosterna arcuata (Moll, 1785 ?). Intermediate host of *Macracanthorhynchus hirudinaceus.*

Melolontha vulgaris Fabricius, 1775. Intermediate host of *Macracanthorhynchus hirudinaceus.*

Onthophagus taurus (Linnæus, 1758). Intermediate host of *Gongylonema pulchrum.* (Other species of the genus *Onthophagus* also probably serve in this capacity.)

Phanæus splendidulus (Fabricius, 1781). Intermediate host of *Macracanthorhynchus hirudinaceus.*

Class **MYRIAPODA** Ruthe, 1832. This class comprises tracheate arthropods in which there is a head, bearing antennæ and jaws, and a trunk, made up of a number of similar segments, provided with leg-like appendages. There are two subclasses, **Progoneata**, in which the genital apertures are situated toward the anterior end of the body, and **Opisthogoneata**, in which the genital apertures are situated at the posterior end of the body. These arthropods are commonly called "millipedes." The order **Diplopoda** Lankester, 1904, consists of forms with apparent segments, each of which, with the exception of the first three, bears two pairs of legs. Species of the genus *Julus*, as well as *Fontaria virginiensis* (Drury, 1770), have been found to serve as intermediate hosts of *Hymenolepis diminuta.*

II. The Mollusca.—The molluscs are metozoan forms, such as the snails, bivalves, squids, devil-fishes and chitons, which have the common characteristics of being fleshy organisms lacking segmentation, of having a reduced celom or body cavity, and of having, as a rule, an exoskeleton, which frequently takes the form of a shell. Members of practically all classes of the phylum serve as intermediate hosts of helminthic parasites. The classes **Gastropoda** (snails) and **Lamellibranchia** (bivalves) are particularly involved in this capacity; they are the obligatory intermediate hosts of trematode infections. Human trematode infections in their intermediate stage are harbored only by fresh-water or amphibious snails. In general these hosts belong to two groups, the gill-breathing forms, which have an operculum, and those breathing by means of a lung and lacking an operculum.

Some specialists depend almost exclusively on the form and characteristics of the shell for the classification of the gastropods. Most workers, however, feel that the internal anatomy of the animal is very important. This latter group particularly stresses the diagnostic importance of the radula, or tritulating ribbon inside the mouth, in determining the family, genus and species relationship. While it is impossible in this synopsis to give these characteristics in detail, figures of typical radular patterns are included with the list of species incriminated in human fluke infections.

Class **GASTROPODA** Cuvier, 1798. This group consists of forms with asymmetrical organization, with a well-developed head, usually bearing contractile tentacles, and with an external shell which is spirally coiled, at least in the larval stage. There are two subclasses, the **Streptoneura** and the **Euthyneura**.

.Subclass **Streptoneura** Spengel, 1881. In this group the visceral nerve commissure is twisted into a figure "**8**." The species are usually diecious. There are two orders of this subclass, the **Aspidobranchia** and the **Pectinobranchia**. The former group consists of a relatively few forms, having a radula with numerous rows of teeth, consisting of a central tooth, two to five laterals, and numerous marginals arranged like the frame-work of a fan. No member of this order is involved in human trematode infections. The latter group consists of a large number of forms, having a radula provided with seven rows of teeth. The species are operculate and usually have gills.

Order **PECTINOBRANCHIA** Reeve, 1842. There are two suborders, the **Stenoglossa**, characterized by having a proboscis, a pallial siphon and a "poison gland," and the **Tænioglossa**, char-

acterized by the absence of these organs. Only the latter group contains human fluke infections.

Suborder **Tænioglossa**. There are two superfamilies, **Heteropoda**, with a laterally flattened foot and adapted to swimming, and the **Platypoda**, with a ventrally flattened foot and adapted to creeping.

Superfamily PLATYPODA. There are many families belonging to this superfamily. Certain of these contain species which serve as the intermediate hosts of human trematode infections.

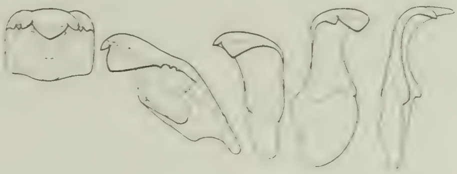

FIG. 282

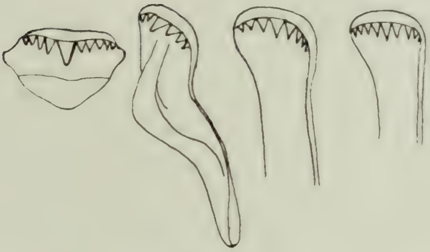

FIG. 283

FIGS. 282 and 283.—Radula patterns of the family Melaniidæ. Fig. 282, *Melania hainanensis*. (After Walker in Faust and Khaw, Am. Jour. of Hygiene.) FIG. 283, *Melanoides tigrina*. (After Annandale, Prashad and Kemp, Records of the Indian Museum.)

Family *MELANIIDÆ* Gray, 1840. (Fresh-water forms.) The members of this group have a broad snout hollowed out in front; separate tentacles, at the base of which are found the pedunculated eyes; a broad short foot, provided with furrowed margins; a mantle which is fringed or festooned, and single leafletted gills which are stationary. The shell, which is usually darkly colored, is dextrally wound, turricated, usually imperforate, and often eroded at the summit, cleanly cut or sinuous at the base, and provided with a spirescent horny operculum. Radula patterns are illustrated in Figs. 282 and 283. Species of the type genus *Melania* are involved as intermediate hosts in important fluke infections.

Melania (*Sulcospira*) *ebenina* Brot, 1883. First intermediate host of *Paragonimus westermani and Metagonimus yokogawai*. Distribution, Lower Yangtze Valley, China.

M. (*Sulcospira*) *extensa* Mts., 1894. First intermediate host of *P. westermani* and *Metagonimus yokogawai*. Distribution, Korea.

M. (*Sulcospira*) *gottschei* Mts., 1886. First intermediate host of *P. westermani* and *M. yokogawai*. Distribution, Korea.

M. (*Sulcospira*) *hongkongensis* Brot, 1874. Possible first intermediate host of *Clonorchis sinensis*. Distribution, South China coast.

M. (*Sulcospira*) *libertina* Gould, 1859. A very polymorphic species. First intermediate host of *P. westermani*, *M. yokogawai*, and *Stamnosoma formosanum*. Distribution, Japan, Korea, South China, Formosa. The most important species of the genus in human fluke dissemination.

M. (*Sulcospira*) *multicincta* Mts., 1894. First intermediate host of *P. westermani*. Distribution, Korea.

M. (*Sulcospira*) *nodiperda* Mts., 1894 and *M. nodiperda* var. *quinaria* Mts., 1894. First intermediate hosts of *P. westermani* and *M. yokogawai*. Distribution, Korea.

M. (*Sulcospira*) *obliquegranosa* Smith, 1878. First intermediate host of *P. westermani*, *M. yokogawai*, *Monorchotrema taichui*, *Stamnosoma formosanum*. Distribution, Formosa.

M. (*Sulcospira*) *paucicincta* Mts., 1894. First intermediate host of *P. westermani*. Distribution, Korea.

M. (*Sulcospira*) *reiniana* var. *hidatchiensis* (Brot) Pilsbry, 1902. First intermediate host of *Monorchotrema taihokui* and *Stamnosoma formosanum*. Distribution, Formosa.

M. (*Melanoides*) *tuberculata* (Müller, 1774). First intermediate host (?) of *P. westermani*. Also host of *Cercaria pleurolophocerca* Sons., the probable larval stage of *Heterophyes heterophyes*. Extensive distribution through Ethiopian, Oriental and Sino-Japanese regions, and even known from Micronesia.

M. (*Nyassia*) *nodocincta* Dohrn, 1865. Intermediate host of *Schistosoma hæmatobium* (?) in Central Africa.

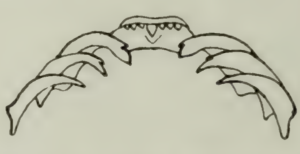

Fig. 284.—Radula pattern of the family Ampullariidæ. (Reprinted by permission from "Fresh Water Biology" by Henry B. Ward and the late George C. Whipple, published by John Wiley & Sons, Inc.)

Family *AMPULLARIIDÆ* D'Orbigny, 1842. (Fresh-water forms.) The members of this group have a snout divided into two tentaculiform processes; two long tentacles with a pair of pedunculated eyes at their outer base; two cervical appendages, of which

the left is modified into a siphon; a branchial chamber divided by a partition, with a single large monopectinate gill and a small rudimentary gill on the right and a "lung" on the left. The radula pattern is illustrated in Fig. 284. Shell large, turbinate, umbilicate, provided with a large oval opening into which fits a horny operculum with excentric nucleus. One species of the type genus *Ampullaria* is said to be involved in human fluke infection.

Ampullaria luteostoma Swainson, 1822–1823. First intermediate host (?) of *Paragonimus westermani* in Venezuela.

Family *VIVIPARIDÆ* Gill, 1863. (Fresh-water forms.) The snout of members of this family is entire, trunk-like; the tentacles are elongate conical, with pedunculated eyes on the outer aspect. Shell of moderate to large size, dextral, turbinate, imperforate or subperforate. Operculum horny, strongly scarred on inner surface. The radula pattern is illustrated in Figs. 285 and 286.

Cleopatra bulimnoides (Olivier, 1804). Host of *Cercaria pleurolophocerca* Sons., the probable larval stage of *Heterophyes heterophyes*. Distribution, Egypt.

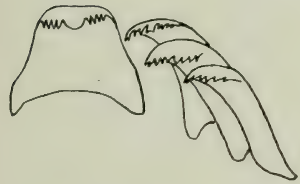

FIG. 285

FIG. 286

FIGS. 285 and 286.—Radula patterns of the family Viviparidæ. (FIG. 285 reprinted by permission from "Fresh Water Biology" by Henry B. Ward and the late George C. Whipple, published by John Wiley & Sons, Inc; FIG. 286, after Walker in Faust and Khaw, Am. Jour. of Hygiene.)

Family *RISSOIDÆ* H. and A. Adams, 1858. (Both fresh-water and salt-water forms.) The members of this group have a simple or transversely cleft foot; long subcylindrical tentacles; a mantle with a smooth border; a male intromittent organ which is external, above the head, usually toward the right. The shell is small (usually under 1 cm.). spiral, dextral, and is provided with an oval or semilunar aperture. The operculum is horny, at times calcareous. The jaws are tessellated; the radular formula is 2, 1, 1, 1, 2, the central tooth of the radula having one or more basal denticles. Only fresh water forms are involved in human trematode infections. Of the five or more subfamilies only the **Triculinæ** and the **Bythiniinæ** concern helminthologists.

Subfamily *Triculinæ* Annandale, 1924. The shell of these species is conical, conoidal or turricated and slender; the operculum is small, thin, horny and capable of being drawn into the interior of the shell. The radula patterns are illustrated in Fig. 287*A*, *B*, *C*. There are two closely related genera of this subfamily which serve as the intermediate host of the Oriental blood fluke. The shells of both types have a thickened peristome. These forms are amphibious.

Oncomelania hupensis Gredler, 1881. Characterized by having prominent longitudinal ridges on the shell. Intermediate host of *Schistosoma japonicum*. Distribution, the Yangtze Valley, China.

Katayama nosophora Robson, 1915. This species has an elongate smooth shell, with eight whorls. Intermediate host of *S. japonicum*. Distribution, Japan, and coastal China from Shanghai to Canton. *K. fausti* and *K. fausti* var. *cantoni* of Bartsch (1925) are referable to this species.

Katayama formosana (Pilsbry and Hirasé, 1905). This species has a shell which is somewhat shorter than *K. nosophora,* has less than seven whorls, and lacks external sculpturing. Intermediate host of *S. japonicum* in Formosa.

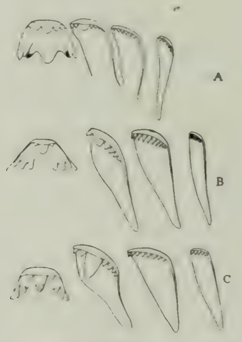

FIG. 287.—Radula patterns of the subfamily Triculinæ (family Rissoidæ). *A*, *Oncomelania hupensis; B*, *Katayama nosophora; C*, *K. formosana*. (*A*, original; *B*, *C*, after Annandale in Faust and Meleney, Am. Jour. of Hygiene.)

NOTE.—Species of *Katayama* are confused at times with species of the terrestrial form, *Opeas*, which, however, among other differences lack an operculum and are much paler in color. Species of *Oncomelania* are frequently confused with young forms of *Melania tuberculata*, which, however, have more severe sculpturing.

Subfamily *Bithyniinæ* Stimpson, 1865. The shell of these species is ovate or subglobose, smooth to the naked eye or with spiral ridges; the operculum is thick and calcareous, wholly concentric or with a small central or subcentral spiral nucleus. The lips are sharp or more or less thickened and reflected. The central tooth of the

radula has several basal denticles. The radula patterns are illustrated in Figs. 288, 289 and 290. Members of two genera are involved as intermediate hosts of *Clonorchis sinensis* in the Far East.

Parafossarulus striatulus (Benson, 1842). Shell ovate-conic, with thickened peristome; with conspicuous spiral sculpturing. This species is the most important first intermediate host of *Clonorchis sinensis*. Distribution, China, Japan, Korea, Formosa and French Indo-China. The form in Japan is usually referred to the variety *japonicus* Pilsbry, 1901.

FIG. 288

FIG. 289

FIG. 290

FIGS. 288, 289 and 290.—Radula patterns of the subfamily Bithyniinæ (family Rissoidæ). Fig. 288, *Parafossarulus striatulus;* Fig. 289, *Bithynia fuchsiana;* Fig. 290, *B. longicornis.* (After Walker in Faust and Khaw, Am. Jour. of Hygiene.)

Bithynia fuchsiana von Möllendorf, 1888. Shell conic, imperforate or perforate, macroscopically smooth, without an umbilical carina. Experimentally found to serve as first intermediate host of *Clonorchis sinensis*. Probably the major host in North China and a lesser host in Central and South China. Distribution, throughout China.

Bithynia longicornis Benson, 1856. Shell globose, imperforate. Distribution from Peking to Tonkin. Probably a minor first intermediate host of *Clonorchis sinensis* throughout the area.

Subclass **Euthyneura** Spengel, 1881. In this group the visceral nerve loop lies beneath the intestinal canal and is consequently not affected by the tortion to which that organ has been subjected. The aquatic members of this subclass all belong to the order **Pulmonata.**

Order **PULMONATA** Ehrenberg, 1831. These are air-breathing species, provided with a lung and breathing tube, and lacking gills and an operculum. They are divided into two suborders, the **Stylommatophora**, in which the eyes are borne on the extremities of retractile tentacles, and the **Basommatophora**, in which the eyes are situated at the base of contractile tentacles. All species of this order involved in human helminthic infections belong to the second group. They are further restricted to the superfamily **Limnophiloidea.**

Superfamily LIMNOPHILOIDEA (Menke, 1828). The members of this group are fresh-water forms, which usually come to the surface from time to time in order to breathe. The following families are important in human trematode infections.

Family *LYMNÆIDÆ* Brot, 1839. The shell of species of this family is ovoid or elongated, with a dextral spiral. The animal is provided with three smooth jaws. The radula patterns are illustrated in Figs. 291, 292 and 293. All species of this family belong to the type genus *Lymnœa* Lamarck.

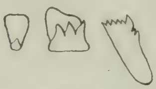

FIG. 291

FIG. 292

FIG. 293

FIGS. 291, 292 and 293.—Radula patterns of the family Lymnæidæ Fig. 291, *Lymnœa natalensis;* Fig. 292, *L. truncatula;* Fig. 293, *L. gedrosiana.* (Fig. 291, after Cawston, Journal of Tropical Medicine and Hygiene; Figs. 292 and 293, after Annandale and Rao, Records of the Indian Museum.)

Lymnœa (*Lymnœa*) *stagnalis* (Linnæus, 1758). This is a polymorphic species, which is apparently the intermediate host of species of *Fasciola* in regions where *L. truncatula* is not present. Distribution, Palearctic.

Lymnœa (*Radix*) *natalensis* Krauss, 1848. Intermediate host of *F. hepatica* and *F. gigantica* in South Africa. Distribution, Eastern and South Africa.

Lymnœa (*Galba*) *truncatula* (Müller, 1774). This polymorphic species is the most common intermediate host of *F. hepatica.* Originally a Palearctic species, it has been introduced into other regions where it has become established. Distribution, Europe, Western and Northern Asia, Northern and Eastern Africa, etc.

Lymnæa (*Galba*) *humilis* Say, 1822. Possible intermediate host of *F. hepatica* in the Southern United States. Distribution, North America.

Lymæa (*Galba*) *viator* d'Orbigny, 1845. Probable intermediate host of *F. hepatica* in South America. Distribution, Central and Southern South America.

Lymnæa (*Pseudosuccinea*) *acuminata* Lamarck, 1822. Probable intermediate host of *F. hepatica* and *F. gigantica* in Central and South China. Distribution, Central and South China, India, etc.

Lymnæa (*Pseudosuccinea*) *gedrosiana* Annandale and Prashad, 1919. Probable intermediate host of *F. hepatica* and *F. gigantica* in Northwestern India, Persia, Baluchistan, etc. Distribution, Northwestern India, Persia, Baluchistan.

Lymnæa (*Fossaria*) *pervia* Mts., 1882. Intermediate host of *F. hepatica* in Japan. Distribution, Sino-Japanese area.

Lymnæa japonica Sowerly, 1872. Intermediate host of *F. hepatica* in Japan. Distribution, Japan.

Lymnæa plicatula Benson, 1855. Probable intermediate host of *F. hepatica* in China. Distribution, China coast and Formosa.

Lymnæa oahuensis Souleyet, 1852. Intermediate host of *F. hepatica* in Hawaii. Distribution, Hawaiian Islands.

Lymnæa rubella Lea, 1843. Intermediate host of *F. hepatica* in Hawaii. Distribution, Hawaiian Islands.

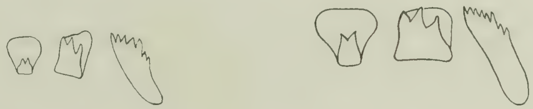

FIG. 294.—Radula patterns of the family Bulinidæ. *A*, *Bulinus* (*Isidora*) *forskali*; *B*, *Physopsis africana*. (After Cawston, Journal of Tropical Medicine and Hygiene.)

Family *BULINIDÆ* Germain and Neveu-Lemaire, 1926. The shell of species of this family is sinistrally coiled, ovoid, globose or elongated, with a spire, either short or elongated, and more or less obtuse at the summit. The radula patterns are illustrated in Fig. 294*A* and *B*. Two genera of the family, *Bulinus* and *Physopsis*, harbor human trematode infections.

Bulinus (*Isidora*) *contortus* (Michaud, 1829). Most important intermediate host of *Schistosoma hæmatobium*. Distribution, Northern Africa from Egypt to Morocco, Congo basin, Sudan, Mesopotamia, Palestine, Sicily, Corsica, rare in France.

Bulinus (*Isidora*) *dybowskyi* Fischer, 1891. Intermediate host *S. hæmatobium*. Distribution, Egypt, Tunis, Algeria.

Bulinus (*Isidora*) *innesi* "Bourguignat" Pallary, 1909. Intermediate host of *S. hæmatobium*. Distribution, Nile Valley.

Bulinus (*Isidora*) *tropicus* (Krauss, 1848). Intermediate host of *S. hæmatobium* and *Fasciola hepatica* (?). Distribution, Southeast Africa.

Bulinus (*Pyrgophysa*) *forskali* (Ehrenberg, 1831). Intermediate host of *S. hæmatobium*. Distribution, Tropical and Eastern Africa.

Physopsis africana Krauss, 1848. Intermediate host of *S. hæmatobium*, *S. mansoni*, and *S. bovis*. Distribution, Eastern Africa from Abyssinia to Natal.

Physopsis globosa Morelet, 1868. Probable intermediate host of *S. hæmatobium* in Central and West Africa.

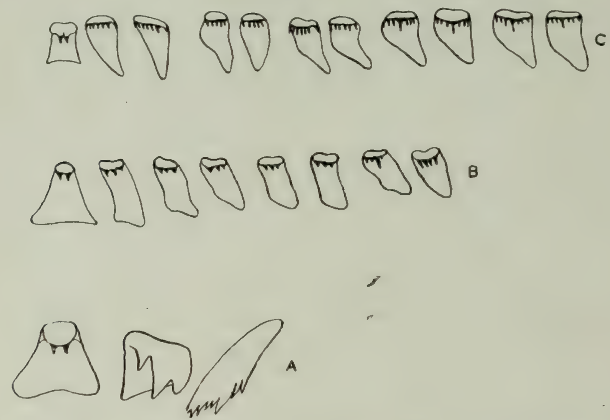

FIG. 295.—Radula patterns of the family Planorbidæ. *A*, *Planorbis pfeifferi; B*, *Hippeutis umbilicatus; C*, *Segmentina calathus*. (*A*, after Cawston, Journal of Tropical Medicine and Hygiene; *B*, after Annandale, Prashad and Amin-Ud-Din; *C*, after Annandale and Prashad, Records of the Indian Museum.)

Family *PLANORBIDÆ* H. and A. Adams, 1858 (?). The shell of species of this family is discoidal, sinistral, or superficially dextral, or spiral with a very low spire. The animal is sinistral and the tentacles are cylindrical. The shell of species of the subfamily **Planorbinæ**, the group which concerns medical zoölogists, is always discoidal. The radula patterns of these species are illustrated in Fig. 295*A*, *B* and *C*. The following species of the type genus *Planorbis* and the genus *Segmentina* are involved in human fluke infections.

Planorbis (*Planorbis*) *metidjensis* Forbes, 1839, and *P.* (*Planorbis*) *metidjensis* var. *dufouri* Graells, 1846. Intermediate hosts of *Schistosoma hæmatobium*. Distribution, Northwest Africa; variety, Spain and Portugal.

Planorbis (*Planorbis*) *boissyi* Potiez and Michaud, 1838. Intermediate host of *S. mansoni*. Distribution, Nile Valley and Erytria.

Planorbis (*Planorbis*) *sudanicus* Martens, 1870. Intermediate host of *S. mansoni* in Nyasaland. Distribution, common in Eastern and Central Africa.

Planorbis (Planorbis) pfeifferi Krauss, 1848. Intermediate host of *S. mansoni.* Distribution, Southeast Africa, including Natal, Zululand, Lorenço-Marques, Rhodesia, Transvaal, and Bechuanaland.

Planorbis (Planorbina) olivaceus Spix, 1827. Intermediate host of *S. mansoni.* Distribution, Bahia (Brazil).

Planorbis (Planorbina) centrimetralis Lutz, 1918. Intermediate host of *S. mansoni* in Pernambuco (Brazil). Distribution, Northern Brazil.

Planorbis (Planorbina) guadeloupensis Sowerby, 1821–1825. Intermediate host of *S. mansoni.* Distribution, Venezuela, Colombia, the Guianas, parts of Northern Brazil, Guadeloupe, Trinidad, Porto Rico, Hayti, etc.

Planorbis (Hippeutis) cœnosus Benson, 1850. Intermediate host of *Fasciolopsis buski.* Distribution, India, French Indo-China, South China, Formosa.

Segmentina schmackeri Clessin, 1886. Intermediate host of *F. buski.* Distribution, Eastern China.

Segmentina hemisphærula Benson, 1842 (= *Planorbis largeillierti* Dunker, 1867). Intermediate host of *F. buski.* Distribution, Eastern China and adjacent islands, including Formosa.

Segmentina nitidella (Martens, 1877). Intermediate host of *F. buski.* Distribution, Japan and Eastern China.

VERTEBRATE INTERMEDIATE HOSTS.

Essentially all main groups of vertebrate animals are involved as intermediate hosts of human helminthic infections. Fishes, frogs, snakes and birds are, in all recorded instances, second intermediate hosts. The mammals serving in this capacity are, in some cases, second intermediate hosts; in others, the sole intermediate hosts.

I. Fishes Serving as Intermediate Hosts.—Except in a few uncertain cases in which the life cycles are incompletely known the fishes involved in human helminthic infections are all fresh-water species. A few of these forms may be caught in salt or brackish water, as illustrated by the mullet (*Mugil* spp.), but even these fishes are primarily fresh-water animals which migrate into salt water at the mating season. Helminths which have been found to exist in their larval stages in various fresh-water fishes consist of certain pseudophyllidean cestodes, all of the members of the opisthorchoid and heterophyoid trematodes of which the life cycles are known, and the nematode *Dioctophyme renale.* Fishes which serve as second intermediate hosts of pseudophyllidean cestodes incur these infections through active ingestion of infected copepods, which constitute an important food supply of the fishes. Practically any plankton-feeding fish in fresh-water lakes or other large clear

inland body of water is liable to infection, provided that conditions are such that the copepod host is subject to infection. Fishes which serve as second intermediate hosts of *Opisthorchis, Clonorchis, Heterophyes, Metagonimus,* and other species of opisthorchoid or heterophyoid trematodes, secure their infection by the active attack and lodgment in their subcutaneous and muscular tissues of the cercarial stage of the fluke, which becomes encysted as deeply in the tissues as it is able to penetrate. Although the species of fishes differ in different endemic areas, practically any fresh-water fish which happens to be near the molluscan hosts of these flukes at the time the cercariæ are emerging from the mollusc is liable to attack and penetration. Only the European ide (*Idus idus*) has thus far been found to harbor the advanced larval stage of *Dioctophyme renale.*

II. Frogs, Snakes and Birds.—According to studies by Japanese investigators, which have been confirmed by the author, *Diphyllobothrium "mansoni"* may be found in its sparganum stage in several species of frog and snakes. Joyeux and Houdemer (1928) have found that certain birds may also harbor this stage of this tapeworm or a closely related species. Chandler (1925) has found the advanced larval stage of *Gnathostoma spinigerum* in certain snakes.

III. Mammals.—Mammals other than man may occasionally harbor the sparganum stage of *Diphyllobothrium "mansoni."* The pig serves as the intermediate host of *Tænia solium* and *Echinococcus granulosus;* the ox, as the intermediate host of *T. saginata* and *E. granulosus;* the sheep, as the intermediate host of *Multiceps multiceps* and *E. granulosus.* The pig is also the important source of infection of *Trichinella spiralis* for man.

In all of these helminthic infections of which vertebrates serve as intermediate hosts, with the exception of *Multiceps* and *Echinococcus,* man incurs the infection from raw consumption of the infested flesh of the vertebrate.

Since the known number of species of these vertebrates is large and the number of potential intermediate hosts is even very much greater, it is not possible to list them here. Such hosts as cannot be readily recognized by the student of helminthology should be referred to specialists for determination.

PLANTS AS VECTORS OF HUMAN HELMINTHIC INFECTIONS.

Plants which are involved in the dissemination of human helminthic infections fall into two categories, (1) those which harbor encysted larvæ of fluke infections, and (2) those which are parasitized by plant nematodes. In both cases the helminth is taken into the human body by consumption of the raw plant harboring the parasite. The first group consists of species of worms which are

true parasites of the mammalian body, while the second group includes species which are only accidental "guests" of the human intestinal tract. To the first group of plants belong the various meadow and swamp grasses, and semi-aquatic plants such as cress, on which the cercariæ of *Fasciola hepatica, F. gigantica, Fasciolopsis buski, Dicrocœlium dendriticum* (?) and *Eurytrema pancreaticum* (?) encyst, as well as the true aquatic species, such as the water-chestnut (*Eliocharis tuberosa*) and the water ling (*Trapa natans* and *T. bicornis*), the most common disseminators of *Fasciolopsis buski*. Likewise any of the meadow grasses in endemic foci may serve as vectors for the ensheathed filariform stage of *Hæmonchus contortus* and related strongylate nematodes. In the second group of plants there are included fleshy roots like the radish, turnips, etc., which are infested with rhabdiasid species like *Heterodera radicidola*.

V. THE EXAMINATION OF INTERMEDIATE AND RESERVOIR HOSTS FOR LARVAL AND ADULT STAGES OF HUMAN HELMINTHS.

A few brief suggestions relative to the technique and method employed in obtaining and examining the various groups of intermediate hosts for larval stages and reservoir hosts for the adult stages of helminths parasitic in man will probably be helpful to those individuals who have had elementary instruction in human helminthology and are contemplating the study of a particular problem in a given locality, either in an attempt to elucidate a life history or to secure epidemiological data. This information will be presented primarily according to the classification of the host involved, as presented in the preceding sections, rather than from that of the parasites.

Invertebrate Hosts.—Only larval stages of helminths parasitic in man are found in invertebrate hosts.

I. Arthropoda.—CRUSTACEA.—1. *Copepoda.*—Only free-living species (genera *Diaptomus* and *Cyclops*) have thus far been incriminated as intermediate hosts of human helminths. These organisms are small creatures but are readily visible with the unaided eye, living in relatively quiet pools or puddles, either constituting permanent or temporary bodies of water. They are frequently associated with green algæ (*e. g.*, "pond scum"). They may be collected by sweeping suspected water with a muslin dip-net, allowing most of the water to drain out, pouring out the concentrated plankton into a large photographic developing tray and transferring to large jars or aquaria, from which they may be later picked out for examination. Individuals may be placed temporarily on a microscopic slide under a cover-glass to determine if they are naturally infected. The larvæ both of tapeworms (*Diphylloboth-*

rium spp. and *Drepanidotænia lanceolata*) and of the Medina worm, if present, will be found in the body cavity of the copepod, and can be seen under low power of the microscope. Since larvæ of other species of tapeworms are frequently harbored by these crustaceans attention must be paid to the characteristics of the larval stages of the human tapeworms which develop in these hosts. In order to allow the larvæ to escape from *Cyclops* or *Diaptomus* the posterior extremity of the abdomen may be dissected off, whereupon the larvæ will emerge from the opening and can be studied in greater detail. In order to infect larvæ-free *Diaptomus* or *Cyclops* with *Diphyllobothrium* larvæ fully-embryonated eggs or free-ciliated larvæ are placed in a small container with the copepods. The free-swimming larvæ will be ingested by the copepods and in susceptible hosts will penetrate through the intestinal wall to the body cavity. Heavily infested copepods are likely to die shortly after infection and will not allow the larvæ to mature. Appropriate species of *Cyclops* may be infected with dracunculus larvæ by placing the larvæ discharged by a female worm in the same medium. The larvæ will break through the intestinal wall into the body cavity and become inactive in that location, remaining so until they come in contact with gastric juice.

2. *Decapoda.*—Fresh-water crayfishes and crabs harbor only one human helminth larva, that of *Paragonimus westermani.* Only those species which live in association with species of molluscs of the genera *Melania* and *Ampullaria* (?) in endemic areas of this infection are subject to suspicion. The animals may be caught by hand and placed temporarily in tin cans with perforated lids. For examination the carapace of the animal is first dissected off. Then portions of the gills are removed to shallow Petri dishes and any small spherical objects found are dissected out and examined under slight pressure with low power of the microscope. Unless these encysted larvæ conform to the type originally distinguished by Yokogawa (Fig. 117) from other encysted fluke larvæ they are not *Paragonimus* larvæ. If the gills are found infected the liver and muscles are likely to be even more heavily parasitized. These tissues may be examined by using a "trichina-press."

INSECTA.—1. *Diptera.*—**Nematocera** and **Brachycera Homodactyla.** These forms, including mosquitoes, midges and gnats of the **Nematocera** and *Chrysops* of the **Brachycera Homodactyla**, are intermediate hosts of filariid worms. Wild flies may be caught (1) at the time they are taking a blood meal by carefully placing over each one a test-tube and withdrawing it after the fly has released its hold on its victim, or (2) by using the same technique in collecting them from the outside of a bed-net, or (3) by collecting them from hiding places around buildings during the day if they are nocturnal feeders, or (4) by sweeping with a fine muslin or bolting-cloth net any vegetation

in which they are hiding. For examination they are first killed with chloroform, the legs and wings removed, and the body placed on a microscopic slide in a drop of physiological salt or Locke's solution. Under a dissecting microscope the head is removed from the thorax by use of fine dissecting needles. In late infections with filariid larvæ the agamofilariæ will frequently emerge of their own accord from the anterior end of the thorax or the posterior end of the head, particularly if the proboscis is in contact with physiological Locke's solution. If this does not occur the exoskeleton should be dissected off the thorax and the thoracic muscles carefully teased apart. Similarly the head portion should be dissected. In early infections larvæ may be found in the fatty bodies of the abdominal cavity, or, a few hours after ingestion of infective blood, still within the gastric lumen or penetrating through the stomach wall. In attempting experimental infections of these several groups of flies essentially the same technique of examination is employed, except that the early stages of development are looked for first. Frequently the nematoceran species suspected of harboring a filarial infection require to be fixed in alcohol, imbedded, stained and sectioned, in order to determine the exact location of the larvæ in their bodies.

2. *Siphonaptera.*—Species of this order found on man, dogs, cats and rats are potential intermediate hosts of *Dipylidium caninum* or *Hymenolepis diminuta.* They may be anesthetized by bringing a camel's hair brush moistened with chloroform in contact with them and for preservation removed with forceps to a chloroform bottle. For dissection each flea is placed on a slide in a drop of saline solution. Larvæ of these tapeworms, if present, will be found in the body cavity of the animal. They must be specifically differentiated from other tapeworm larvæ possibly harbored by these insects.

3. *Mallophaga.*—The technique for examination of lice is similar to that for *Siphonaptera.*

4. *Lepidoptera.*—The insect is first killed in chloroform vapor and dissected on a large microscopic slide or in a small Petri dish. Larvæ of *Hymenolepis diminuta,* if present, will be found in the body cavity.

5. *Orthoptera.*—The insect is first killed in chloroform vapor, placed in a shallow Petri dish, the legs, wings and mouth parts dissected off and the body cavity first opened up. Gordiacea, if present, will be found coiled in the body cavity. *Hymenolepis diminuta* and *Davainea* larvæ will also be in this locality. *Gongylonema* larvæ and those of *Moniliformis moniliformis* may be found encysted in the peritoneal wall but are more likely to be encysted in the thoracic muscles.

6. *Coleoptera.*—The insect is first killed in chloroform vapor, placed in a shallow Petri dish, the legs, wings and hard parts of the

under side of the thorax and abdomen dissected off, and the body cavity then laid open. *Hymenolepis diminuta* larvæ, when present, are found in the body cavity; nematode and acanthocephalan larvæ are most likely to be found encysted in the thoracic muscles. Since these beetles harbor many species of larval nematodes special care should be taken not to confuse larvæ of non-human species with those which may occur in man.

Myriapoda.—For examination of species of *Julus* and *Fontaria* for *Hymenolepis diminuta* the technique is similar to that for *Coleoptera.*

II. Mollusca.—Molluscs are the first intermediate hosts of all digenetic flukes. As such they constitute an extremely important group to the student of trematode infections. They are no less important to the medical helminthologist than to the biologist, but because the number of species of trematodes of man is relatively small compared with the very large total of such organisms found in their intermediate stages in molluscs, the difficulty of differentiating the human forms during their molluscan phases is very great. Only the specialist in this group is prepared to attempt such differentiation and he is at times baffled by the large number of forms which he encountered and the very few reliable characters which are available for the determination of species and even genera of this class of helminths. Fortunately all of the human trematodes utilize only gasteropod molluscs and these are further limited to freshwater and amphibious species.

For study the gastropods (snails) which are suspected on epidemiological evidence of harboring intermediate stages of human trematodes are collected and taken or sent to the laboratory. Living non-operculate (*e. g.*, pulmonate) species cannot be shipped any great distance without considerable difficulty. They may be packed in damp (not wet) moss in a perforated container and if kept cool may survive for several days *en transit.* On the other hand operculate snails, particularly the smaller forms, if they are first dried off and packed in dry moss in a perforated wooden box will survive shipment for many days. Specimens of *Oncomelania* and *Katayama* may be easily transported in this way for a month or more and will survive desiccation up to approximately six months. In preparing the fleshy body of the snail for examination the calcareous shell is carefully cracked by use of bone cutters and the inner portion of the spire "unscrewed" from the viscera. The organ most commonly parasitized is the liver, which occupies the apical part of the snail. In ordinary practice this organ is separated from the remaining viscera and muscular portion and is teased apart in a watch-glass in one-half normal saline solution, which is approximately the saline concentration of the snail tissues. Trematode infections, if present, will usually be situated in the inter-

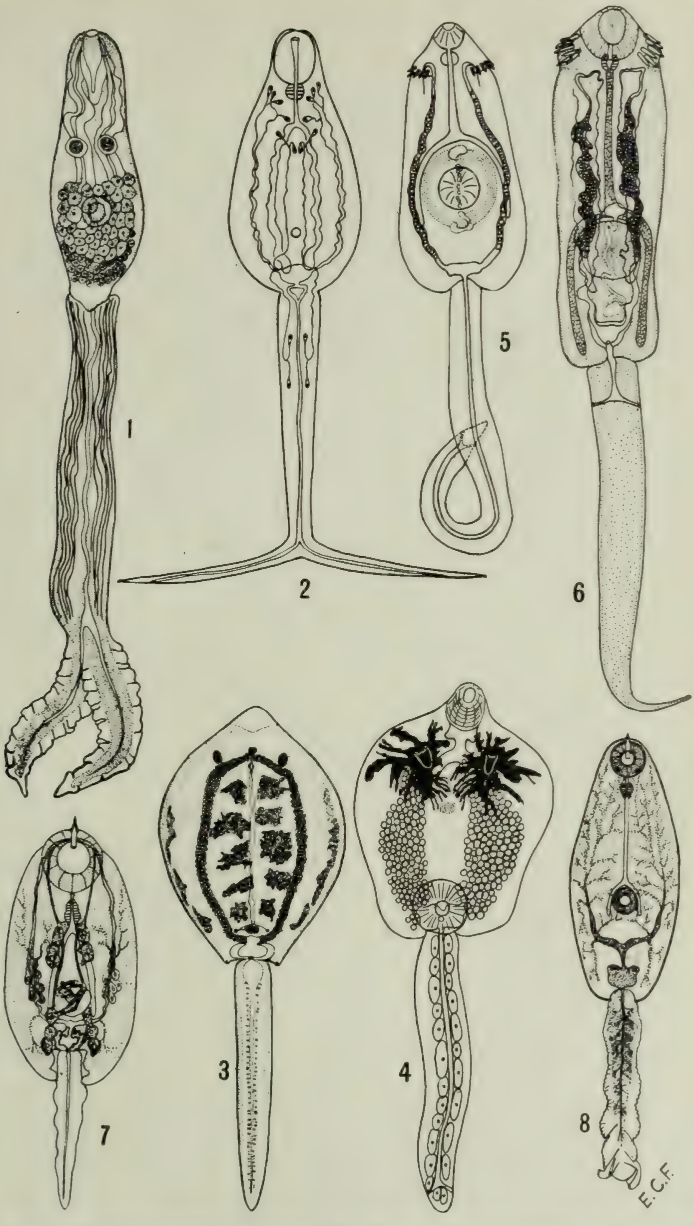

FIG. 296.—Cercariæ representative of non-human trematodes found during intermediate stages in fresh-water snails. 1, *Cercaria gigas* (blood fluke); 2, *C. quattuorsolenata* (holostome); 3, *C. pellucida* (monostome); 4, *C. frondosa* (amphistome); 5, *C. catenata* (echinostome); 6, *C. trivolvis* (echinostome); 7, *C. crenata* (stylet cercaria); 8, *C. racemosa* (stylet cercaria). (After Faust, Journal of Parasitology and Illinois Biological Monograph, vol. iv.)

FIG. 297.—*Cercaria syringicauda*, typical of the larval stage of the superfamily **Hemiuroidea,** to which the accidental human parasite, *Isoparorchis trisimilitubis* belongs. (After Faust, Parasitology.)

hepatic lymph spaces and in the region between the liver and the primary reproductive organs. The dissected tissues are viewed under low power of the microscope. In moderate or heavy infections sporocysts or rediæ and cercariæ in various stages of development can easily be found. For careful study the individual specimens are transferred to a slide and mounted with a cover-glass. The best opportunity for observing details of the inner structure of either the parthenita (sporocyst or redia) or cercaria presents itself after the specimen has been somewhat compressed and usually just before the organism disintegrates. The accompanying figures (Figs. 296 and 297) illustrate common types of the cercarial stage of trematodes not occurring in man, which the author has found in various species of snails, and which may possibly be confused with human types. (Compare with Figs 26, 67*A*, 74, 96, 107 and 115). In some cases encysted larvæ (metacercariæ) may be found in the gills, lungs, wall of the respiratory siphon or attached to the mantle folds of snails. None of these forms are known to be human parasites.

III. Vertebrata.—*Fishes*—In piscine hosts human trematode infections occur in the encysted (*e. g.*, encapsulated) stage after the cercaria has invaded the tissues of the fish and has lost its tail. These cysts may be attached to the under side of the scales or to the cartilaginous tissues of the head and gills, or may be imbedded in the subcutaneous or muscular tissues. The presence of a certain type of trematode cyst in the more superficial tissues is usually indicative of a heavier infection in the muscles. The scales may be scraped off the fish's body for examination; cysts imbedded in the flesh may be determined either by scraping off bits of muscle and examining as a slide film or by use of a "trichina" press; or a section of the muscle may be cut out, imbedded in paraffin, sectioned, stained and then examined.

Pseudophyllidean cestodes which utilize fishes as intermediate hosts, are found in the sparganum or mature larval stage in these hosts. In infected specimens these larvæ will be found to occur as small milky-white ribbons among the muscle elements and may be readily recognized and dissected out of the flesh.

Larvæ of *Dioctophyme renale* occur in adventitious cysts in the piscine host.

Frogs, Snakes and Birds.—The only human helminths known to occur in these hosts are the sparganum stage of *Diphyllobothrium* species. These occur as milky-white ribbons in between the muscular elements and are most commonly found along the spinal column, and in frogs in the thigh region and in snakes along the ribs. They also frequently occur in the subcutaneous tissue and in heavy infestations give a puffy appearance to the animal.

Mammals.—Sparganum infection is usually found in the same region in mammals as in lower vertebrates, but in the sparganum

stage of *Diphyllobothrium* in the hedgehog, *Erinaceus dealbatus*, the pectoral muscles are most usually parasitized. Cysticerci are most commonly found in the heart muscles, hypoglossus and "tenderloin" regions, but may occur in all muscular tissues and to a lesser extent in other organs. *Multiceps multiceps* is most frequently encountered in the brain. *Echinococcus* cysts are most common in the vicinity of the liver, but may develop in any tissue of the body. *Trichinella* cysts are present in all striped muscle, but can be diagnosed most readily from a piece of diaphragm flattened in a "trichina" press.

IV. Plant Vectors.—In all of the species of aquatic or semi-aquatic plants which serve as vectors of human helminthic infections, including flukes of the species *Fasciola hepatica, F. gigantica, Fasciolopsis buski, Dicrocœlium dendriticum* (?) and *Eurytrema pancreaticum* (?), and several species of strongylate nematodes, the mature larval worms (adolescariæ) are encysted as little spherules (trematode infections) or ensheathed filariform larvæ (*Hæmonchus contortus et al*) on the outside of the vegetation and never penetrate the plant tissues. The fluke cysts appear as minute milky-white concretions attached to the surface of the plant. These larvæ may be discovered by carefully examining vegetation in endemic foci with a good high-power hand lens. They can then be scraped off onto a slide, mounted and studied under a dissecting or compound microscope.

In all of the organisms which serve as intermediate or reservoir hosts of human helminthic infections, the helminths peculiar to the human host constitute a relatively small part of the total number of species harbored by these animals. This is particularly true of the stages of trematodes in molluscs and fishes and of nematodes in biting diptera and beetles. For this reason the greatest care must be taken to determine that the larval helminths found in non-human hosts are actually the ones which infect man. To this end both morphological and experimental data are usually required in order that the evidence may be thoroughly convincing.

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INDEX.

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B

C

F

G

I

M

N

U

V

W

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